



Faculty of Resource Science and Technology

**Water Quality and Sediment Characteristics of the Upper Baram River,
Sarawak**

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Water Quality and Sediment Characteristics of the Upper Baram River,
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DECLARATION

From here, the thesis is declared with accordance of the regulations from Universiti Malaysia Sarawak (UNIMAS). The work is genuine, unless indicated otherwise or acknowledged as references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

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ABSTRACT

Rivers are essential for water supply and function as habitats for aquatic flora and fauna. Therefore, baseline information of water quality and sediment characteristics of the upper Baram River is important for sustainable management of the environment due to anthropogenic activities in the river basin. A total of 31 stations were established for the study. Study covers approximately 170 km of the upper Baram River, from 0.5 km downstream of Lio Mato to 0.2 km downstream of the estuary of Kemenyeh River. The sampling was conducted once in Jan, July and Sep 2015 from upstream, midstream and downstream sections of the upper Baram River. Another two trips were conducted in Jan and Mar 2016 at the downstream section in order to study the effect of rainy season. Overall, this study found that the means of specific conductance, transparency, Chl-*a*, and NO₂-N of the main river stations were significantly lower concentrations than the tributaries. Meanwhile, the means of DO, turbidity, and TSS at the main river showed significantly higher concentrations as compared to its tributaries. Furthermore, this study also found that the mean of sand in sediment at the main river was significantly higher as compared to its tributaries. Meanwhile, means of clay and organic matter in sediment at the main river were significantly lower concentrations as compared to its tributaries. The significantly higher organic matter that present in the sediment at stations 6, 23, 25, 26, and 28 at the tributaries were believed to be due to the discharge of human wastewater and animal wastes from both longhouses and logging activities and logging camp. With logging activities, stations 6 (Selungo River), and 7 (Temendan River), 20 (Patah River), 22 (Btg Hit River), and 24 (Btg Tanan River), showed significantly higher TP, NO₂-N and Org-N concentrations. In addition, station 27 at Long Kesseh was observed to have low pH, high turbidity, and high TSS. Furthermore, station 25, Jertang River was observed to have significantly lower pH and

higher OM, TOC, TKN, and TP concentrations in the sediment than the other stations. With both logging and longhouses activities nearby, stations 14 and 15 showed high turbidity, high TSS and high COD in the river. Furthermore, station 28, Nakan River was observed to have significantly higher OM, TOC, TKN, and TP concentrations in the sediment. Based on WQI, only stations 26 and 28 improved after rainy events, while, stations 22 and 25 became worse after the rainy event. PCA of the water grouping revealed that logging activities are closely related with high turbidity and TSS. This study found that a total of 26,547,196 kg/day of TSS, 570,960 kg/day of BOD₅, 40,141 kg/day TP, and 272,524 kg/day of Org-N flowed from station 27 to the downstream area of the Baram River. Sebatu River (station 8), and Sela'an River (station 9) showed significantly higher loadings of TSS and BOD to Baram River than the others. This study shows that Baram River was polluted by logging activities and waste from longhouses. Therefore, proper management of land use that reduces pollution needs to be introduced.

Keywords: Baram River, water quality, sediment characteristics, logging, longhouses

Kualiti Air dan Ciri-ciri Sedimen di Hulu Batang Baram, Sarawak

ABSTRAK

Sungai adalah penting untuk bekalan air dan ia berfungsi sebagai habitat flora dan fauna. Oleh itu, maklumat bagi kualiti air dan ciri-ciri sedimen ke hilir Sungai Baram adalah penting untuk pengurusan alam sekitar yang mampan disebabkan aktiviti antropogenik di sekeliling sungai. Sebanyak 31 stesen telah dipilih untuk kajian ini. Kajian ini meliputi kira-kira 170 km dari hilir Sungai Baram, iaitu dari 0.5 km hilir Lio Mato kepada 0.2 km hilir Sungai Kemenyeh. Pensampelan itu dijalankan sekali pada Jan, Julai dan Sep 2015 dari bahagian hulu, tengah dan hiliran Sungai Baram. Dua lagi pensampelan telah dijalankan pada Jan dan Mar 2016 di bahagian hiliran untuk mengkaji kesan musim hujan. Secara keseluruhan, kajian ini mendapati bahawa ketelusan, Chl-a, dan NO₂-N di sungai utama mempunyai kepekatan yang lebih rendah berbanding dengan anak sungai. Selain itu, DO, kekeruhan, dan TSS di sungai utama menunjukkan kepekatan yang lebih tinggi berbanding dengan anak sungai. Tambahan pula, kajian ini juga mendapati bahawa kepekatan dalam pasir di sungai utama adalah lebih tinggi berbanding anak sungai. Sementara itu, kepekatan dalam tanah liat dan bahan organik di sungai utama adalah lebih rendah berbanding anak sungai. Bahan organik yang signifikan tinggi di dalam sedimen di stesen 6, 23, 25, 26, and 28 adalah disebabkan oleh pelepasan air sisa dan haiwan dan bahan buangan manusia dari kedua-dua rumah panjang dan aktiviti pembalakan dan kem pembalakan. Stesen 25, Sungai Jertang dengan aktiviti pembalakan sahaja menunjukkan pH lebih rendah secara signifikan, OM, kepekatan TOC, TKN, dan TP lebih tinggi dalam enapan secara signifikan. Sementara itu, bagi stesen 28, Sungai Nakan dengan kedua-dua pembalakan dan rumah panjang, diperhatikan bahawa kepekatan OM, TOC, TKN, dan TP adalah lebih tinggi secara signifikan. Berdasarkan WQI, hanya stesen 26 dan 28, telah bertambah baik selepas hujan,

manakala, stesen 22 dan 25 menjadi bertambah teruk selepas acara hujan. Kumpulan dari PCA atas parameter air dan sedimen mendedahkan bahawa aktiviti pembalakan berkait rapat dengan kekeruhan dan TSS yang tinggi. Diperhatikan bahawa stesen 6, Sungai Selungo, 7, Sungai Temendan, 20, Sungai Patah, 22, Btg Sungai Hit dan 24, Btg Sungai Tanan dan dengan aktiviti pembalakan menunjukkan TP, NO₂-N dan Org-N yang tinggi. Di samping itu, pH telah diperhatikan signifikan rendah, manakala kekeruhan dan TSS adalah signifikan tinggi di stesen 27 di Long Kesseh. Bagi stesen 14 dan 15 di mana wujudnya kedua-dua aktiviti pembalakan dan rumah panjang, kekeruhan, TSS dan COD yang tinggi telah diperhatikan. Kajian ini mendapati bahawa sebanyak 26,547,196 kg/hari TSS, 570,960 kg/hari BOD₅, 40,141 kg/hari TP, dan 272,524 kg/hari Org-N telah dipindahkan dari stesen 27 ke hilir Batang Baram. Pemuatan TSS dan BOD dari Sungai Sebatu (stesen 8) dan Sungai Sela'an (stesen 9) ke Batang Baram adalah yang jauh lebih tinggi daripada stesen yang lain. Kajian ini menunjukkan bahawa Sungai Baram tercemar oleh aktiviti pembalakan dan sisa-sisa dari rumah panjang. Oleh itu, pengurusan penggunaan tanah yang betul yang mengurangkan pencemaran perlu diperkenalkan.

Kata kunci: Sungai Baram, kualiti air, ciri-ciri sedimen, pembalakan, rumah panjang

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LIST OF ABBREVIATIONS

%	percent
°C	degree Celsius
±	plus and minus
≤	less than or equal to
≥	greater than or equal to
<	less than
>	greater than
µg	microgram
Abs	absorbance
APHA	American Public Health Association
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
CaCl ₂	Calcium Chloride
COD	Chemical Oxygen Demand
Conc.	Concentration
DOE	Department of Environment
FAS	Ferrous Ammonium Sulphate
g	gram
GPS	Global Positioning System
HClO ₄	Perchloric Acid
H ₂ SO ₄	Sulphuric Acid
K ₂ Cr ₂ O ₇	Potassium Dichromate
kg	kilogram
KHP	Potassium Hydrogen Phthalate
KH ₂ PO ₄	Potassium Hydrogen Phosphate
K ₂ HPO ₄	Dipotassium Hydrogen Phosphate
KI	Potassium Iodide

km	kilometre
km ²	kilometre square
KMnO ₄	Potassium Permanganate
L	litre
LEL	lowest effect level
M	molarity
m	metre
m ²	metre square
m ³	metre cube
mg	milligram
MgSO ₄	Magnesium Sulphate
min	minute
mL	millilitre
mm	millimetre
Na ₂ HPO ₄	Sodium Hydrogen Phosphate
NaOH	Sodium Hydroxide
Na ₂ S	Sodium Sulphide
Na ₂ SO ₃	Sodium Sulphite
NH ₄ Cl	Ammonium Chloride
nm	nanometre
NWQS	National Water Quality Standards
O ₂	Oxygen
PE	Polyethylene
PCA	Principal Component Analysis
S	Sulphur
SPSS	Statistical Package for the Social Sciences
UV-VIS	ultraviolet visible
WQI	Water Quality Index

CHAPTER 1

INTRODUCTION

1.1 Research Background

Sarawak is the largest state within the Federation of Malaysia with an area of 124,449.51 km² and it is segmented into 12 administrative divisions (Sarawak Government, 2017). According to Food and Agriculture Organization of United Nation (UNFAO) (UNFAO, 2017), at the year of 2014, existing forest in Malaysia amounted to approximately over 0.2 million km² or 67.5 % of total land area which is crucial in maintaining the ecosystem balance. In East Malaysia, the state of Sarawak still has large availability of tropical rainforests with distinctive endemics of flora and fauna. It is about 80 % or approximately 0.1 million km² of Sarawak's forest total land area (Sarawak Government, 2017). Sarawak is rich with natural resources, therefore; the state's economy is heavily dependent on the mentioned resources in the form of hardwood timber, vegetation and fossil fuels (SPU, 2011).

In addition, Sarawak has an equatorial climate (MetMalaysia, 2017). Therefore, the temperature is relatively uniform throughout the year. It has an ideal climate for tropical species of flora and fauna to flourish. Besides, Sarawak experiences two monsoonal seasons. The natural drainage of Sarawak is dominated by two main river systems: the Baram River and the Rajang River (SPU, 2011). According to Department of Irrigation and Drainage (DID) Sarawak, the Rajang River has a length of 560 km with a river basin area of 51,153 km² and it is the largest river in Malaysia (DID, 2017). Meanwhile, the Baram River is about 401 km long with a river basin area of 22,109 km² which is the second longest river in Sarawak state (DID, 2017).

Fresh water is essential to sustain all living organisms. Throughout the world, only 2.5 % of global water is fresh water and they are primarily found in icecaps, glaciers and ground water (USGS, 2017). From the 2.5 % of the fresh water on Earth, only 1.2 % is found in the surface water of lakes, rivers, and swamps and ground water, ice and permafrost (USGS, 2017). Rivers play important roles in sustaining of life inhabit in the natural ecosystem. They also serve as important water source and means of transportation which are essential for human daily activities. Furthermore, it also functions as processing and transferring of organic matters, nutrients turnover and storage of the nutrients (Padmalal & Maya, 2014). In addition, the fast flowing river water constantly mixed due to turbulence which provides nutrients for aquatic organisms, exchange of respiration gases and removal of wastes in the rivers (Padmalal & Maya, 2014). Beside that the river is vital to support the life cycle in nature, it is also widely exploited by humans for its natural resources.

Furthermore, there has been a tremendous increase in the demand for water resources due to the rapid growth in population. According to Department of Statistics Malaysia (DOSM) (2016), in the year 2016, the total population of Malaysia is estimated at 31.7 million with 0.5 million increase as compared to the year 2015, indicating 1.5 % growth of population. As for Sarawak, the total population is 2,471,140 people in the year 2010 (DOSM, 2016) with approximately of 88,800 people settling in Baram, Marudi district, Sarawak (Marudi District Council, 2017). The population increment and economic development had resulted in serious water quality deterioration issue (Ma *et al.*, 2009; Park & Lee, 2002; Ren *et al.*, 2002).

As the urban development still continues, water pollution had led to serious ecological and environmental problems. Water pollution is the contamination of water bodies in the form of environmental degradation occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds. Ma *et al.* (2009) reported that most of the cities generally dispose urban and industrial wastes into the Shiyang River, China without proper treatment which resulted environmental degradation in the Minqin basin. Therefore, conservation and restoration of the river resources are urgently needed.

Nevertheless, the main drivers of the nutrients enrichment in the rivers are the agricultural activities, mainly from diffuse pollution sources which came from excess fertilizer application, and urban point sources, associated with wastewater discharge to the rivers (Cruz *et al.*, 2010) from area sources. Hossain *et al.* (2013) stated that water quality deterioration in eastern part of Peninsular Malaysia especially in Gebeng, Kuantan is the impact of anthropogenic activities due to rapid industrialization. This is due to the discharge of municipal wastes, agricultural and runoff from developing areas into the Tunggak River (Hossain *et al.*, 2012) without proper treatment. The increase in economic development in Malaysia also resulted in more land use such as, urbanization, industrialization and the expansion of agricultural sector (Salih *et al.*, 2013). Such economic growth factors may have adversely affect the water quality of Baram River.

1.2 Problem Statement

Baram River, located in Sarawak is mainly used for agriculture, irrigation and as the main water source for the local residents. The increase in population also increases the demand for freshwater resources. However, agricultural and logging activities pose a serious threat to the water quality of Baram River. There was little information on the water quality and sediment characteristics of the Baram River in the past. Therefore, a comprehensive study on the river water quality and sediment characteristics is of great importance in this project.

1.3 Research Questions

The research questions of this study were:

- I. Is there any difference in water and sediment quality between the main Baram River and its tributaries?
- II. Is there any rainy season effect on the water quality at the main Baram River and its tributaries?
- III. Is there any effect of land usage on the water and sediment quality at the main Baram River and its tributaries?
- IV. What are the quantities of pollutant loadings at the main river from the output of the tributaries?

1.4 Research Hypotheses

The research hypotheses of this study were:

- I. There are differences in the water and sediment quality between the main Baram River and its tributaries.
- II. Rainy season has an effect on the water quality at the main Baram River and its tributaries.
- III. Land usage has effect on the water and sediment quality at the main Baram River and its tributaries.
- IV. The quantity of pollutant loadings from tributaries has effect to the main Baram River.

1.5 Objectives

The objectives of this study were:

- I. to determine water and sediment quality at the main Baram River and its tributaries
- II. to determine the effect of rainy season on the water quality at the main Baram River and its tributaries
- III. to assess effect of land use on the water and sediment quality
- IV. to quantify pollutants loading at the main river and from its tributaries

CHAPTER 2

LITERATURE REVIEW

2.1 Water Quality

Water is a valuable natural resource which is essential for living things. Water is primarily used as drinking water supply, recreational purposes, crops irrigation and livestock watering, industrial process, navigation and shipping, and aquatic ecosystems protection (NSW, 2015). Water quality of a river is correlated to the environment and land use. Besides, weather is also a major factor that impacts the water quality of a river. Water quality parameters are important tools to monitor the environment. The primary purpose of water quality study is to determine whether the river water is polluted or not. The water quality parameters includes the measurement of temperature, dissolved oxygen (DO), pH, specific conductance, transparency, turbidity, total suspended solids (TSS), five days biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), nitrite-nitrogen (NO₂-N), nitrate-nitrogen (NO₃-N), organic-nitrogen (Org-N), ammonia-nitrogen (NH₃-N), total sulphide (TS), and total phosphorus (TP), and total Kjeldahl nitrogen (TKN) in sediment

2.1.1 Physical properties

The water quality parameter, pH, stands for “power of Hydronium” with scales from 0 to 14. The pH value is affected by the dissociated hydrogen ions (Rao, 2002). Acids are substances which release hydrogen ions and it contains more hydrogen ions than neutral water while, bases are substances which accept hydrogen ions and it contains fewer hydrogen ions than neutral water (Rao, 2002). In addition, Jonnalagadda and Mhere (2001) stated that unpolluted streams

normally show a near neutral or slightly alkaline pH value. The increase of pH value was triggered by the increase of the inputs of nutrients from fertilizer, organic materials from sanitation and sediment from deforestation and erosion (de Jong *et al.*, 2015; Shrestha & Kazama, 2007). From the research done by Ling *et al.*, (2010a) at Santubong River, Malaysia, it is reported with high pH value which could be caused by anthropogenic inputs of nutrients that resulted with more algae photosynthesis. Low pH value allowed toxic elements and compounds to become mobile (Amneera *et al.*, 2013). Meanwhile, extremely low pH value is estimated to be toxic to fish through the mobilization of toxic metals and the release of hydrogen sulphide (de Jong *et al.*, 2015).

Specific conductance is a measurement of the ability of a material to conduct electrical current in water. The conductivity of a solution is conventionally determined by the concentration, charge and mobility of the dissolved ions (Miller *et al.*, 1988) and the dissolved ions in the river facilitates the conductance of electrical current. Alternately, conductance reflects the status of inorganic pollution and is a measure of ionized compound in the water (Jonnalagadda & Mhere, 2001). In Ruvu River, Tanzania, high conductivity take place with higher inputs of salts contributed by urban and agricultural areas (Ngoye & Machiwa, 2003). However, Douglas *et al.* (1992) stated that the conductivity level of the rivers is more closely related to the amount of rainfall than the actual discharge from the contributors mentioned. This is because the higher ratio of freshwater as compare to ionized materials lowers the conductivity in the river. Tong & Chen (2002) reported that residential and agricultural land usage inevitability showed strong relationship with conductivity, pH value and BOD. Waste discharges from the residential and agricultural land carry excess nutrients, nitrate and phosphate into rivers and pile up the dissolved ions, hence, high conductivity in water.

2.1.2 Transparency, Turbidity and TSS

Water transparency is a measure of the depth of light penetration into the water. It depends on the amount of particles in the water. Turbidity measurement is used to indicate the clarity of the water (Hach, 2015). In other words, the higher the intensity of scattered light, the higher the turbidity in the water (USGS, 2017). Materials that can cause water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, and plankton and other microorganisms (USGS, 2016; Hach, 2015). Amneera *et al.* (2013) stated that high turbidity observed at Perlis River, Malaysia was because of the soil erosion, runoff factors, fast river flow, and the presence of organic pollutants source in the river.

Total suspended solids (TSS) are particles that are $> 2 \mu\text{m}$ found in the water column and anything $< 2 \mu\text{m}$ is considered as dissolved solid. Sediment is particles that is light enough to be carried by water without touching the stream bed and it is called suspended sediment, and it is visible as cloudy or milky areas of water (USGS, 2017). According to the research of Hossain *et al.* (2013), TSS concentration varied from 1.0 mg/L to 2171.0 mg/L with an overall mean value of 55.48 mg/L, where high TSS concentration was due to the establishment of a new industry and also heavy rain (Hossain *et al.*, 2013). Based on the study done by Amneera *et al.* (2013) and Yang *et al.* (2007), increasing the runoff level which is the rainfall rate will decrease the TSS in river water due to water river dilution.

2.1.3 Chemical properties

Dissolved oxygen (DO) refers to the concentration of oxygen gas dissolved in water. The sources of DO in a water body includes re-aeration from the atmosphere, photosynthetic production from aquatic plants, denitrification and DO inputs (Loucks *et al.*, 2005). Oxygen concentrations in water are high because photosynthesis occurs during daytime (Loucks *et al.*, 2005). This is mainly due to the phytoplankton responses to light and nutrient availability, particularly nitrate in order to support phytoplankton growth (Costanzo *et al.*, 2003). At night, the concentrations drop due to oxygen usage for respiration of aquatic organisms and other variable of oxygen-exhaustion processes (Loucks *et al.*, 2005). The inverse relationship between temperature and DO is a natural process because warmer water is easily saturated, thus, DO is lessen (Shrestha & Kazama, 2007). The results of study conducted by Yang *et al.* (2007) at the Huangpu River, China showed that the low DO concentration during summer season was possibly because of the rising water temperature and microorganisms activities that consumed a large amount of oxygen to metabolize the decaying organic matter. In addition, low DO concentration was also reported to be in correlation with the organic pollutants input particularly domestic wastes (Amneera *et al.*, 2013; Ngoye & Machiwa, 2003).

Nutrients loadings from both urban and agricultural land discharges can cause excessive algae growth and resulted low DO level (Loucks *et al.*, 2005). According to the research done by Hossain *et al.* (2013), the average concentration of DO at Tunggak River, Gebeng, was 2.61 mg/L; which indicated that the water of that area was highly deoxygenated. It was due to the discharge of organic matter and nutrient rich industrial effluents which induced greater microbial activities (Hossain *et al.*, 2013; Amneera *et al.*, 2013; Yisa & Jimoh, 2010). In addition, high organic loadings can reduce DO level to a level that is fatal to the aquatic

ecosystem (Yisa & Jimoh, 2010; Loucks *et al.*, 2005). As a result, fish will take longer time to grow and may die along the growth process, which in turn produced organic pollutants such as proteides that was critically degrading water quality (Ma *et al.*, 2009). In general, DO levels that are less than 3 mg/L stress most of the aquatic organism and at 1-2 mg/L, most of the fishes cannot survive (Fondriest, 2016). Moreover, water with low DO from 2 - 0.5 mg/L is consider hypoxic; while water with less than 0.5 mg/L is consider anoxic (Fondriest, 2016).

Biochemical oxygen demand (BOD) is a measure of oxygen consumed by microorganisms in the decomposition of organic material (Missouri Department of Natural Resources, 2016; Yang *et al.*, 2007; APHA, 2005). BOD₅ test measures the molecular oxygen utilized during a five days incubation period for the biochemical degradation of organic matter and the amount of oxygen used to oxidize inorganic matter, such as rocks, minerals and metals (APHA, 2005). Chemical oxygen demand (COD) is defined as the amount of a specified oxidant that reacts with the sample under controlled condition (Missouri Department of Natural Resources, 2016; APHA, 2005). In other words, COD is a measurement of the oxygen concentration required to oxidize soluble and particulate organic matter in water. According to Amneera *et al.* (2013), the value of COD should be higher than BOD. The trend of BOD was almost similar to the COD as they are positively and significantly correlated (Hossain *et al.*, 2013).

Ling *et al.* (2010a) reported that high BOD can be attributed to untreated or partially treated sewage and discharges from agro-based and manufacturing industries. The increase of COD and BOD concentrations reduces the DO concentration in the water, leaving less oxygen available to support aerobic respiration by microorganisms and promoting anaerobic

decomposition (Ma *et al.*, 2009). From the research conducted by Ling *et al.* (2010b) at Kuching, Malaysia, it was found that the high BOD₅ concentration corresponded to low concentration of dissolved oxygen (DO). This is because oxygen present in the water was used to break down organic matter (Ling *et al.*, 2010b; Yang *et al.*, 2007).

The high COD concentration near Kangar wet market, Perlis, Malaysia was likely due to higher decomposition of organic and inorganic contaminants, dissolved or suspended in water that came from the wet market (Amneera *et al.*, 2013). Moreover, the concentration of COD was higher in the river water especially at the industrial zone which contained a lot of multifarious industries (Hossain *et al.*, 2013). That indicated the presence of both organic and inorganic pollutants from effluents (Hossain *et al.*, 2013).

Abdalla & Hammam (2014) stated that the BOD:COD ratio (biodegradability index) is 0.5:1.0 for raw domestic wastewater and may drop to as low as 0.1: 1.0 for well-stabilised secondary effluent. According to Dahamsheh & Wedyan (2017), the ratio of BOD to COD that is more than 0.6 means the waste considered as biodegradable, if the ratio is between 0.3 to 0.6 then the waste is obligatory to treat it biologically, and if the ratio is less than 0.3 means that biodegradation in the river cannot proceed, therefore, it cannot be treated biologically. In addition, Abdalla & Hammam (2014) stated that biodegradability index (BI) that is less than 0.3 in the river was due to the wastewater generated from industries waste and human activities such as logging activity inhibits the metabolic activity of bacterial seed due to their toxicity.

Chlorophyll-*a* is a colour pigment found in plants, algae and phytoplankton. This molecule is used in photosynthesis, as a photoreceptor which absorbs light energy. High turbidity and the presence of suspended particles in the water will affect the amount of light that penetrate into the water (Neal *et al.*, 2006). With less light available, photosynthetic production will decrease. Water temperature will also affect photosynthesis rates. Neal *et al.* (2006) stated that chlorophyll-*a* concentrations peaked in the spring and summer time when biological activity is at its highest. This is because photosynthesis is initiated and sped up by heat.

2.1.4 Forms of Nitrogen

Nitrogen is important for all plants to survive and comes in various forms such as, nitrate, dinitrogen, ammonium nitrogen, and organic nitrogen (Killpack & Buchholz, 2017). Nitrate nitrogen ($\text{NO}_3\text{-N}$) is an intermediate biological decomposition compounds containing Org-N (Hach, 2015). Nitrates that are present in the soil result from natural biological processes associated with the decomposition of plant residues, organic matter, animal manure and nitrogen fertilizers (Killpack & Buchholz, 2017).

Meanwhile, the main sources of ammonium nitrogen ($\text{NH}_4\text{-N}$) are domestic sewage and livestock farming (DOE, 2017). Yang *et al.* (2007) concluded that high nutrient concentration led to the growth of microorganisms. For instance, if there is a large quantity of organic waste present in the water bodies, it would also need a lot of bacteria to decompose the organic waste. As a result, oxygen concentration in the water body decreased as oxygen is used for the degradation of organic matters and respiration of the bacteria. Due to the high oxygen demand for ammonia oxidation, decreased concentration of DO lead to low nitrification rate in water

body (Ruiz *et al.*, 2006). Low DO concentration will decrease nitrification rate. Consequently, river water contains low $\text{NO}_3\text{-N}$ values with high amounts of TN and $\text{NH}_4\text{-N}$ (Yang *et al.*, 2007). $\text{NO}_3\text{-N}$ is the completed oxidized state of nitrogen (Hach, 2015). $\text{NH}_3\text{-N}$ is produced largely by deamination of Org-N containing compounds and by hydrolysis of urea (APHA, 2005).

Nitrogen gas is the most abundant gas in the atmosphere and nitrogen is also an essential component for all living organisms. Figure 1 shows the nitrogen cycle in the environment. Nitrogen gas (N_2) in the atmosphere is converted to inorganic nitrogen compounds, such as ammonia (NH_3) or ammonium ion (NH_4^+) through nitrogen fixation by nitrogen-fixing bacteria where *nitrogenase* enzyme is involved. Meanwhile, a small amount of nitrogen is fixed through high energy such as lightning and industrial processes (Haber process) which produce ammonia. Some of the NH_3 taken up by plants from soils through assimilation is then converted into nitrite (NO_2^-), and then nitrate (NO_3^-) through nitrification by nitrifying bacteria. Animals then ingest these plants, and converting them into their own body compounds. Decomposers breakdown plants and animals and animal wastes, into organic matter through decomposition. The organic matter is then converted to ammonia through ammonification by ammonifying bacteria. Nitrogen returns back to the atmosphere under anaerobic condition through denitrification by denitrifying bacteria, where nitrate (NO_3^-) is converted to gaseous nitrogen (N_2).

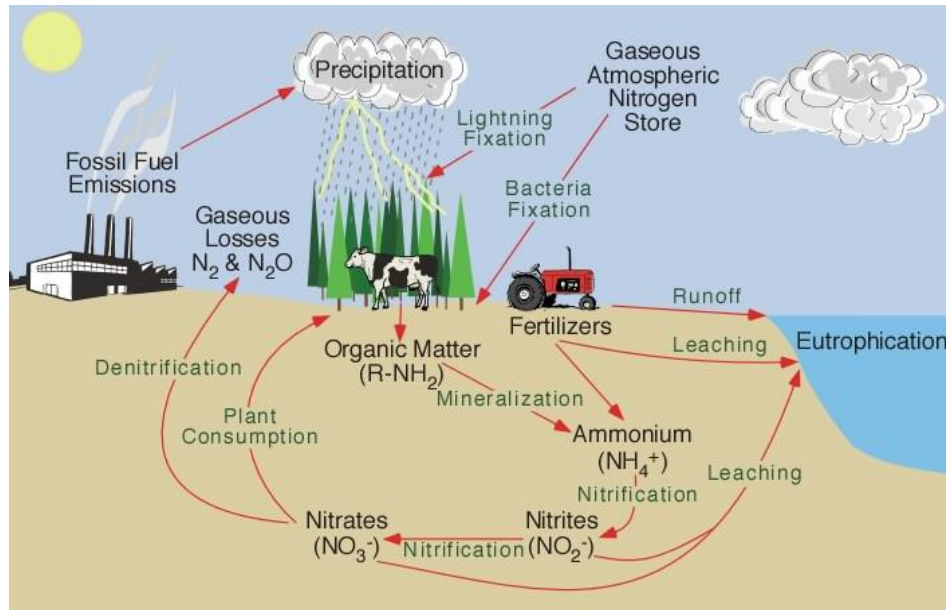


Figure 1: Nitrogen cycle (USEPA, 2017)

2.2 Factors that Affect Water Quality

Factors that affect water quality in the river can be physical, chemical or biological factors. Water quality in a river is primarily affected by pollution from point and diffused sources. Land use, logging activities, oil palm plantation, soil erosion and excessive nutrients discharged into the river can cause water pollution.

2.2.1 Impacts of Land Use

Human activities are the primary factor causing the degradation and poor water quality of rivers. Economic development such as urbanization, agricultural, industrialization activities lead to more intensive land use which deteriorate the water quality of a river (Kibena *et al.*, 2014; Hossain *et al.*, 2013; Salih *et al.*, 2013; Bahar *et al.*, 2008; Douglas *et al.*, 1992). However, land use itself does not affect water quality but the anthropogenic activities on the land use changes could influence the types and degree of pollution (Bu *et al.*, 2014).

Moreover, the changes of land use pattern can cause water pollution due to the increase of population and the development of economic activities (Ngoye & Machiwa, 2003). According to Park and Lee (2002) and Kibena *et al.* (2014), the rapid population growth coupled with industrial and urban development had resulted in serious deterioration of water quality in downstream area of Nakdong River, Korea and Manyame River. In fact, the major concern in the densely populated urban areas is the lack of sanitation facilities and poor disposal systems (Ngoye & Machiwa, 2003) which cause pollution from the area source.

Furthermore, the water quality of receiving water can be affected by human activities through point and non-point source pollution. The inputs of a point source pollution are factories, municipal sewage treatment facilities and large farms that raise livestock (DOE, 2017; Bu *et al.*, 2014; NOAA, 2008; Sliva & Williams, 2001; Carpenter *et al.*, 1998). Point source pollution can cause severe damage to human health and the environment. In the study conducted by Ngoye & Machiwa (2003) in Ruvu River in Tanzania, it was reported that the main factors affecting the water quality are industrial waste products, pesticides and fertilizers contamination and domestic sewage pollution. Two findings of Bu *et al.* (2014) and Zhou *et al.* (2007) at Taizi River basin and northwestern new territories, Hongkong, China respectively, also supported that land use led to pollution by organic matter mostly because of the point source pollution from the domestic sewage inputs, particularly in residential area and livestock production. The large amount of organic waste from livestock which are directly discharged into the river combined with high temperature caused depletion of DO in the receiving waters as a result of oxygen consumption from the decomposition of organic materials in the water (Kannel *et al.*, 2008).

Point source pollution is relatively simple to measure and regulate and can often be controlled by treatment at the source (Carpenter *et al.*, 1998). On the contrary, non-point source pollution commonly refers to the diffuse sources such as soil erosion and runoff from urban areas and farmland caused by heavy precipitation (DOE, 2017; Bu *et al.*, 2014; Amneera *et al.*, 2013; NOAA, 2008; Sliva & Williams, 2001). Consequently, non-point source is difficult to measure and regulate. This is because the pollutants from the non-point source pollution from the runoff are numerous and quite harmful (NOAA, 2008). In fact, rivers are one of the Eco-tourist attractions. This has encouraged the construction of hotels and resorts along the rivers. Thus, the activities of clearing the land become more intensive along the rivers in order to meet the demand in tourism.

2.2.2 Impacts of Logging and Deforestation Activities

A river is blessed with diverse assemblages of flora and fauna. However, due to human activities, such as hotels, resorts and road construction, river ecosystem has undergone major degradation in the water quality. Deforestation is a major factor that impact the water quality of a river (Mathai *et al.*, 2010; Douglas *et al.*, 1992;). Moreover, excessive exploitation of the forest in the surrounding of Berasau River, Johor, Malaysia for timber has contributed to soil erosion and landslide events (Nor Zaiha *et al.*, 2015). Furthermore, the demand for timber hike in global market has prompted tropical countries including Malaysia to supply timber via exploiting forest (Nor Zaiha *et al.*, 2015). In addition, timber and timber products from Sarawak are the fourth largest contributor to the State's Gross Domestic Product (GDP) after oil, gas, and palm oil (SCORE, 2017).

Logging activities in tropical forest require transport network for timber transferring to be built which often resulted in unmanageable major ecological disturbance (Nor Zaiha *et al.*, 2015). An interesting study conducted by Douglas *et al.* (1992) reported that when the logging road construction was almost completed, the suspended sediment load in Sungai Steyshen Baru, Sabah, was almost ten times more than the undisturbed forest areas. Furthermore, after a series of storms that occurred at Sungai Steyshen Baru, Sabah, from late November to mid-December, it produced daily sediment discharges exceeding 10 ton km⁻² (Douglas *et al.*, 1992). This indicated that after logging activities there is serious erosion occurring over the remaining area.

Deforestation is recognized to leave negative impact on the environment itself. The impacts of logging activities includes the degradation of the valuable forest that threatens the survival of the endemically biodiversity, sharp escalation of soil erosion and landslides that decrease the water quality, increase in emission of carbon dioxide and drastic climate change that lead to massive natural disasters (Nor Zaiha *et al.*, 2015; Reboredo, 2013). In addition, the development of swidden agriculture, commercial logging and oil palm plantation have been considered as the primary factor of degradation and loss of rain forests in Southeast Asia (Ichikawa, 2007).

The activity of deforestation reduces the canopy covers, thus leading to eroding river banks and sedimentation (Nor Zaiha *et al.*, 2015). In other words, switching of the vegetation land to oil palm plantation often leads to soil erosion resulting in the deposition of sediment at the bottom of the nearby stream (Ling *et al.*, 2011). Furthermore, new and present housing and new road development results in the removal of vegetation thus exposing the soil to erosion (Ling *et al.*, 2010a).

2.2.4 Impacts of Suspended Sediment

In aquatic environments, the impacts of sediment have been a public concern for many decades. In fact, climate change and human activities such as deforestation have accelerated the erosion rate and increased the sediment load (Wei *et al.*, 2011; Willing, 1999; Cohen *et al.*, 1993) into the river. Sediment that enters the river degrades the quality of water for drinking, to support wildlife and the land surrounding the streams. Furthermore, nutrients transported by sediment can activate blue-green algae that release toxins and can cause people to get ill (USGS, 2017). Fine sediment affects rivers by reducing the water clarity and therefore, impact on primary producers and consumers in aquatic food chains (NIWA, 2016; Howard-Williams *et al.*, 2008; Cohen *et al.*, 1993). The water that is polluted by sediment becomes cloudy and murky which prevents natural vegetation from growing and aquatic life from hunting foods in the water (NIWA, 2016; USGS, 2017). High levels of turbidity limits the penetration of sunlight into the water column, therefore limit the growth of algae, rooted aquatic plants, and affect the hunting activities of the aquatic organisms (Cohen *et al.*, 1993). In addition, suspended sediment can clog fish gills, reducing the resistance capabilities to potential disease, lowering growth rates, and affecting fish egg and larvae development (NIWA, 2016; USGS, 2017).

Forest increases the soil stability because their roots bind the earth together (USEPA, 2017). When land is cleared for urban development, the exposed soils become vulnerable and prone to erosion and can cause massive quantities of sediment to be washed into nearby waterways through surface runoff, especially after an intense rainfall (USGS, 2017; Wei *et al.*, 2011) which led to severe soil erosion. At the Baram River that was covered in the recent study, the land use changes in the river region also bring heavy loads of sediment into the Baram River (Nagarajan *et al.*, 2015).

2.2.5 Soil Erosion

Soil erosion near a river is a natural occurring process that refers to the runoff of topsoil by physical force of water (Ontario, 2016). Soil erosion can be accelerated during rainfall events (Ren *et al.*, 2002; Vega *et al.*, 1998). The impact of raindrops on the soil surface can break down and disperse soil aggregates; materials like fine sand, silt, clay and organic matter when become lighter aggregates are easier to be removed by the raindrop splash and runoff water (Ontario, 2016). Therefore, the water becomes more turbid when the soil is washed down into the river by rain. During raining season, greater progression of water flow across surfaces increased the erosion rates which also increased the rates of particulate matter entering the river channel (Sliva & Williams, 2001). Sliva & Williams (2001) reported that the storm water runoff from the urbanized areas had high degree of influence on the water quality of Rouge River, Duffins Creek, and Highland Creek watershed, Ontario, Canada.

Nor Zaiha *et al.* (2015) found that high concentration of COD and TSS at Berasau River, Johor, Malaysia, was likely due to the river receiving high runoff and high rate of erosion during monsoon season. Water runoff not only leads to soil erosion but also increase the acidity of the receiving water body, as the soil particles comes along with nutrients that cause water to be acidity (Nor Zaiha *et al.*, 2015). Furthermore, Hossain *et al.* (2013) mentioned in his studies at eastern part of Peninsular Malaysia, that higher sediment concentration in river water was observed (2171.0 mg/L) during higher rainfall due to higher transport capacity with water force is accompanied by higher erosion rate. The high erosion rate caused by surface runoff directly affected the water quality. Ismail & Ibrahim (2015) also reported that higher sediment concentration observed in the streams was due to surface runoff delivering sediment from the upper segment of river.

Agricultural land is affected by soil erosion due to the loss of natural nutrients and applied fertilizers (Tong & Chen, 2002). On the Atlantic slope, soil erosion is closely related to the farming activities (Meade, 2014; Wei *et al.*, 2011). Existing organic matter from the soil, residues and applied manure and pesticides can be readily transported off the agricultural field with the eroded soil (Ontario, 2016). Furthermore, eroded soil can disrupt fish habitat and degrade downstream water quality (Ontario, 2016).

Human activities such as deforestation, construction, and crops plantation are the main contributions to soil erosion (Meade, 2014; Carpenter *et al.*, 1998). In addition, the increase of population enhanced the development of the industry and agricultural sectors also contribute to soil erosion. These drastic developments caused deforestation resulting in the surrounding bare soil to experience gradual erosion during rainfall (Salih *et al.*, 2013; Wei *et al.*, 2011). The weathered soil then rundown into the rivers and formed a murky layer which blocks out sunlight from penetrating the water. Therefore, it threatens the survivability of aquatic organism with lesser or no sunlight (Salih *et al.*, 2013).

2.2.6 Sources of Nutrients

Nutrient pollution caused by excessive fertilizer that ends up in the river is one of the most widespread environmental problems that lead to major human health issues. Nitrogen and phosphorus are the main nutrients for aquatic ecosystems. They support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water (USEPA, 2017).

Excessive nutrients such as nitrogen and phosphorus were released into the water bodies caused by an increase in human activities. Nutrients content in rivers increase with the human population expanding and development of economies (Ibáñez *et al.*, 2008; Park & Lee, 2002; Ren *et al.*, 2002). Momentous nutrients increase has encourage the growth of algae which threaten the water quality, food resources and existing habitats, and decrease the oxygen concentration level for the fish and other aquatic life (US EPA, 2017; Carpenter *et al.*, 1998). Moreover, storm water runoff could also add nutrients to the river. Fertilizers, yard and pet waste, and certain soaps and detergents with nitrogen and phosphorus contents that are disposed off by residents, also contributed to nutrient pollution if not properly disposed (US EPA, 2017; Ling *et al.*, 2010b; Yisa & Jimoh, 2010). Moreover, forest fire at the middle Mahakam wetlands, East Kalimantan also resulted in nutrient availability increase through runoff and deposition of sediment (de Jong *et al.*, 2015). Wastewater from the sewer and septic systems that is not processed accordingly will discharge the nutrients into the waterways (US EPA, 2017; Ling *et al.*, 2010b; NOAA, 2008;).

2.2.6.1 Agriculture

Agriculture is one of the major contributors of nutrient to water body. The largest sources of nitrogen and phosphorus pollution are mainly from animal manure, excessive fertilizer applied to crops and fields, and soil erosion in general (USEPA, 2017; Ismail & Ibrahim, 2015; Cao *et al.*, 2012; Jonnalagadda & Mhere, 2001). The use of nitrogen fertilizers for agricultural purposes usually comes in three nitrogen forms namely ammonium, nitrate or urea (Costanzo *et al.*, 2003). Howarth (2008) also reported that the use of fertilizer in China is heavy, almost 10-fold greater than U.S. usage, per area of cultivated land.

From the research finding conducted by Kibena *et al.* (2014) at Manyame River, there is an escalating trend of water pollution due to urban agriculture fertilization and organic pollution from urban area. Research done by Ngoye & Machiwa (2003) also supported that high concentrations of nutrients in Ruvu River, Tanzania was due to high inputs of waste from urban and agricultural areas. In addition, Yisa and Jimoh (2010) stated that nitrate value that exceed the permissible limit could be due to leachates from waste disposal, sanitary landfills, over application of inorganic nitrate fertilizer or improper manure management practice (Chapman, 1996). Furthermore, a similar study done by Bu *et al.*, (2014) at Taizi River basin, China stated that high amounts of rainfall causes the fertilizer from agriculture land overflow into nearby river, that leads to river water quality deterioration. Ngoye and Machiwa (2003) found that the highest level of $\text{NO}_3\text{-N}$ concentration ever recorded was during dry (0.5 mg/L) and rainy (0.62 mg/L) seasons occurring at the station which is neighbouring the market place that is poor with sanitation and lack of waste management facilities.

Nitrogen retention has different means other than inputs or outputs of nitrogen to the freshwater system. Three processes contribute to nitrogen retention: denitrification, sedimentation and uptake by aquatic plants (Saunders & Kalff, 2001). Ammonium-nitrogen ($\text{NH}_4\text{-N}$) acts as an indicator of the pollution from excessive usage of ammonia, especially from fertilizers, human and animals wastes, and by-products from industrial manufacturing processes (Ismail & Ibrahim, 2015). High $\text{NH}_4\text{-N}$ can degrade the aquatic status of the urban stream and discharge of untreated sullage adds oxygen-demanding substances, nutrients and toxic elements into the water (Amneera *et al.*, 2013).

On the other hand, during raining days, higher levels of $\text{NH}_4\text{-N}$ was also observed at Ruvu River, Tanzania (16.24 mg/L) which was caused by fertiliser used in farms (Ngoye & Machiwa, 2003). Meanwhile, high concentration of $\text{NO}_3\text{-N}$ corresponds to low concentration of $\text{NH}_4\text{-N}$ due to the oxidation reaction of $\text{NH}_4\text{-N}$ that converts to $\text{NO}_3\text{-N}$ (Ling *et al.*, 2010a; Yang *et al.*, 2007). Based on the study done by Ghani *et al.* (2009) at Sungai Batang Benar, Malaysia, the high ammonium is mainly caused by the combination of point and non-point source due to the influx occurrences in dry and wet season.

Furthermore, domestic wastewater was reported to show a highly positive correlation between nutrients and residential area. It is conceivable to say that it comes from fertilizers used on agricultural land and residential gardens, and domestic effluents (Bahar *et al.*, 2008). Meanwhile, high concentration of phosphorus was observed at Ruvu River, Tanzania, contributed by the wastewater and phosphorus fertilizers inputs from dairy farms and diffuse sources, for instance, washing at the river side (Ngoye & Machiwa, 2003). Diffuse pollutants enter water through surface runoff and disposure produced from livestock (Howard-Williams *et al.*, 2008). Meanwhile, sulphate found in the river likely came from domestic wastewater and fertilizers (Bahar *et al.*, 2008).

2.2.6.2 Domestic or Household Wastes

Human population expansion is overwhelming. The increase in the number of residential areas deteriorates the water quality. The discharge of the household wastewaters from a town or a city flows into the sewer system, and ends up at the local Wastewater Treatment Plant (WWTP). Wastewater will be discharged into river or stream after being treated (NOAA, 2008). Although

the influent to sewage treatment works (STWs) is usually treated prior to being discharged into rivers, it is known that untreated effluent will be discharged straight into the river during large rainfall events, via combined sewage overflows (CSOs) and STW bypass channel (Owens & Walling, 2002).

Ling *et al.* (2010b) stated that the discharge of household wastewater into surface water may present multiple concerns mainly higher concentration of BOD₅, and TSS. Ahearn *et al.* (2005) also stated that nitrate-N loading was greatly impacting the stream nitrate levels when a WWTP was built. Moreover, a lack of sewage disposal, solid waste disposal system and adequate sanitation facilities are reported to threaten the water resources in urban areas of Shiyang River, China (Ma *et al.*, 2009). In addition, wastewater from residential areas containing soaps and detergents that are used for washing and laundry has nitrogen and phosphorus substances which contribute to the nutrients pollution (USEPA, 2017; Yisa & Jimoh, 2010). High phosphorus concentration observed at Sampadi River, Malaysia was likely caused by household phosphorus products from laundry and septic tank discharge (Ling *et al.*, 2011). Ling *et al.* (2010b) also said that wastewater from residential areas was high in BOD₅ due to overflow from septic tank where black water was only partially treated. Meanwhile, greywater that is untreated is channelled to surface water through a network of storm water drains (Ling *et al.*, 2010b).

2.2.7 Eutrophication

Nitrates and phosphates are the nutrients that all the plants need to grow. Phosphorus is essential to the growth of organisms and can as well be the nutrient that limit the primary productivity of a body of water (APHA, 2005). Likewise, nutrients like $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$ and TP are the main nutrients that enriched water bodies and caused eutrophication (USEPA, 2017; Yang *et al.*, 2007).

Figure 2 shows the eutrophication process in river. Eutrophication stimulates an increased growth of algae and aquatic weeds which depletes the oxygen in water and it became a hypoxic condition (USEPA, 2017; Carpenter *et al.*, 1998). Excessive nutrients such as fish feed and faeces discharged in the water will promote algae growth that poses a great risk to the health of aquatic organisms (USEPA, 2017; Ling *et al.*, 2010a; Ling *et al.*, 2010b; Ling *et al.*, 2010c; Yang *et al.*, 2007). When oxygen is completely depleted by the decomposition of algae, the wide-spread of algal blooms (red or brown tides) will condition the water into anoxic stage by releasing toxins (USEPA, 2017; Carpenter *et al.*, 1998). In addition, toxic algal blooms will affect tourism due to its foul odours and unsightly views; poisoned fish and shellfish adversely affecting recreational and commercial fisheries (USEPA, 2017; Carpenter *et al.*, 1998). Furthermore, the highly toxic, volatile chemical compound produced by this algae can cause long term neurological damage to people who come in contact (Carpenter *et al.*, 1998).

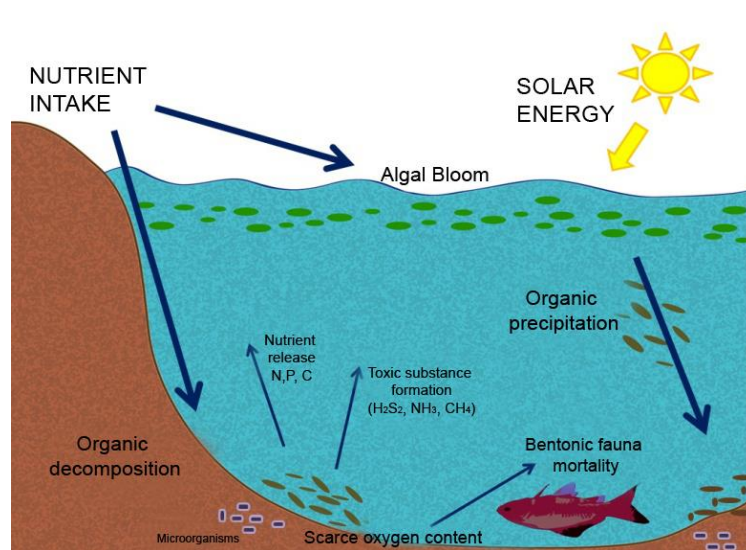


Figure 2: Eutrophication

Figure 3 shows the phosphorus cycle in the environment. Phosphorus in soil is generally little, and this often limits plant growth. Phosphorus enters the environment during precipitation and weathering of rocks which cause the release phosphate ions (PO_4^{3-}) and other minerals into the soils. This inorganic phosphate is then distributed into soils and water. Plants take up inorganic phosphate from the soil and animals consume the plants. The remains of plant and animal and their waste products were decomposed and the organic phosphate is returned to the soil. Bacteria in the soils can break down the organic matter to inorganic forms of phosphorus through mineralisation. Phosphorus in water can be incorporated into sediments over time.

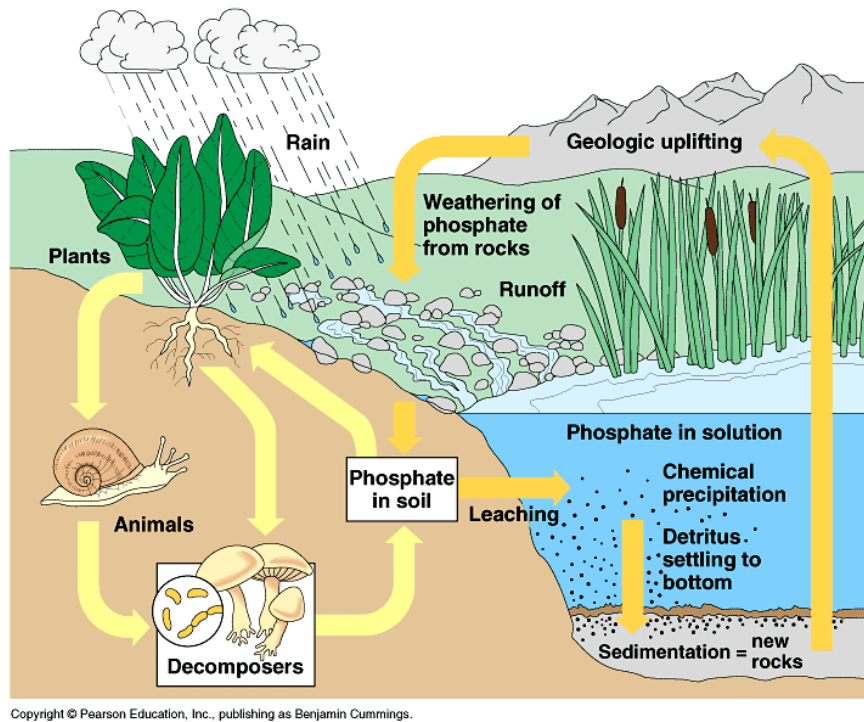


Figure 3: Phosphorus Cycle (Pearson, 2011)

2.3 Water Quality Index (WQI)

Water quality index (WQI) is an important tool that relates the different parameters of the water quality. It is notably defined as water quality assessment through the chemical parameters of surface water and also reflects the composite influence of different water quality parameters (Yisa & Jimoh, 2010). A WQI provides grade that expresses overall water quality of the river based on several water quality parameters. WQI calculation involves six basic parameters, namely dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen ($\text{NH}_3\text{-N}$), pH and total suspended solid (TSS) (DOE, 2017; Amneera *et al.*, 2013). WQI serves as indicator to evaluate the water pollution status whether the water falls in clean, slightly polluted or polluted categories (DOE, 2016).

2.4 National Water Quality Standards for Malaysia (NWQS)

National Water Quality Standards for Malaysia (NWQS) is to classify the water whether falls in Class I, II, III, IV or V (DOE, 2017; Amneera *et al.*, 2013). In Malaysia, a total of 1064 water quality monitoring stations located at 143 river basins are monitored and reported in the year 2007 (DOE, 2017). Out of these 1,064 monitoring stations, 638 water samples (60%) were found to be clean, 376 samples (35%) slightly polluted and 50 samples (5%) were polluted (DOE, 2017). According to DOE Malaysia (2017), in 2015, the major pollutants detected were BOD, NH₃-N and TSS.

2.5 Sediment Characteristics

Sediment compose of loose sand, clay, silt and other soil particles material that settle at the bottom of a body of water (USEPA, 2017). There are three main sources of sediment. Sediment can come from the soil erosion of upland areas, the decomposition of plants and animals and re-mobilization of stored sediment through channel processes (USGS, 2017). Sediment deposited on the river banks and flood plains of a river is often enriched with mineral and nutrients which makes an excellent farmland (USGS, 2017; Nasnolkar *et al.*, 1996).

2.5.1 Classifications of Sediment

Most of the geologists categorize sediment primarily based on their grain size and all the size classifications of sediment distinguish between sand, silt, clay and gravel fractions (Winterwerp & Kesteren, 2004; Kettler *et al.*, 2001; Bittelli *et al.*, 1999; Gee & Bauder, 1986). Sand gives soil volume and porosity; silt gives it resilience; clay provides nutrients and strength to the soil and retains water (Kettler *et al.*, 2001). However, too much sand makes a soil loose and sterile

while, too much silt makes it mucky and too much clay makes it impenetrable whether wet or dry (Kettler *et al.*, 2001).

In aquatic environment, sediment can be at two different stages which are known as suspended sediment (SS) or bedded sediment (BS). SS is primarily fine inorganic particles of clay and silt (typically < 0.063 mm), fine sand (0.063 - 0.250 mm) and particulate organic matter, that is floating or suspended in the water column, concurrently, bedded sediment is settled on the bottom of a water body (USEPA, 2017). Individual sediment grains are classified on the basis of the physical dimensions of single particles. The four major grain size classes are < 0.063 mm: fine particles of inorganic clay and silt, well-decomposed organic matter typically found in suspended sediments; 0.063 – 0.250 mm: fine sands that are suspended; 0.250 – 2 mm: small bedload, medium to coarse sands; and > 2 mm: coarse bedload, mainly gravels and small cobbles (Kettler *et al.*, 2001; Gee & Bauder, 1986). The grain size of the soils is shown in Appendix 28.

Soil texture is a qualitative classification instrument used in the field and laboratory for agricultural soils to determine classes based on their physical texture. Soil textures are classified by the fractions of each soil separate (sand, silt, and clay) present in a soil. Classifications are typically named for the primary constituent particle size or a combination of the most abundant particles sizes, e.g. "sandy clay" or "silty clay". A fourth term, loam, is used to describe a roughly equal concentration of sand, silt, and clay, and lends to the naming of even more classifications, e.g. "clay loam" or "silt loam".

Figure 4 shows the soil texture diagram for the sediment. It affects the soil-water retention characteristics, leaching and erosion potential, plant nutrient storage, and organic matter dynamics (Kettler *et al.*, 2001). Similarly, a sediment is classified based on the distribution of grain size within a given volume (Figure 4). Particle size analysis (PSA) distribution is the measurement of the size distribution of individual particles in a soil sample (Gee & Bauder, 1986).

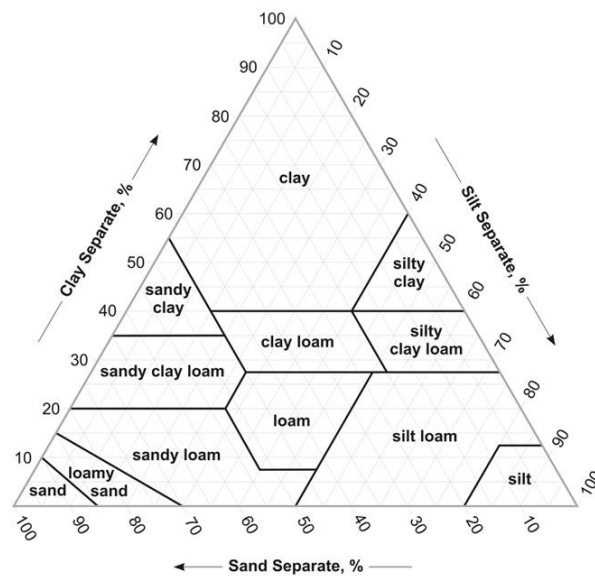


Figure 4: Soil Texture Classification Ternary Diagram for fine-grained sediments (USDA, 2017)

2.5.2 Importance of Sediment

Sediment is necessary for the development of aquatic ecosystems which act as nutrient replenishment, and the creation of benthic habitat and/ or spawning areas (Czuba *et al.*, 2011). These benefits transpire when sediment deposition with suspended particles settle down at the bottom of a water body (Czuba *et al.*, 2011). This settling often occurs when water flow slows down or becoming stagnant, thus, heavy particles can no longer be supported by the bed turbulence (Czuba *et al.*, 2011).

The deposition and storage of fine-grained sediment within the channels of river systems has several important implications for the delivery and fate of sediment-associated nutrients and contaminants (Walling *et al.*, 2003; Walling, 1999). However, high levels of sedimentation in rivers lead to physical disruption of the hydraulic characteristics of the river channel. Moreover, sediment deposits in rivers can alter the flow of water and reduce or increase water depth (USGS, 2017). This can cause serious impacts on navigation through reduction in depth of the river channel. It can increase flooding activities because of reductions in capacity of the river channel to efficiently route water through the drainage basin (USGS, 2017).

Furthermore, sediment is the sink for nitrate and oxygen and also the sources of ammonium ions (Trimmer *et al.*, 1998; Nedwell & Trimmer, 1996). In the research done by Trimmer *et al.* (1998), it was found that sedimentary organic carbon and sedimentary total nitrogen content was the highest at the muddy sites predominantly silt and clay and lowest at the very fine sandy sites. This suggested that organic and inorganic particulate matter was mainly deposited at that area (Trimmer *et al.*, 1998).

2.5.3 Nutrients Pollution in Sediment

In agriculture, the primary source of nutrient pollution in sediment is the inclusion of fertilizers and animal manure, which are both rich in nitrogen and phosphorus. From a research done by House & Denison (2002) on the Rivers in the Thames catchment (Wey, Blackwater, Thame and Kennet), the River Swale in Yorkshire, the River Blackwater showed the concentration of phosphorus in the sediment increased from 19 $\mu\text{mol/g}$ at the upstream sites to 131 $\mu\text{mol/g}$ at

downstream of the sewage inflow. This indicates phosphorus is accumulated in sediments downstream of sewage outfalls (House & Denison, 2002).

Previous studies at the River Swale, Yorkshire, UK on the total phosphorus content of fluvial sediment in rural and industrialized river basins showed that the total phosphorus (TP) content is generally within the range of 500 to 1500 $\mu\text{g/g}$ (Owens & Walling, 2002). Besides, the study showed that TP content of the main urban and industrial areas ranged from $< 2000 \mu\text{g/g}$ in the headwater areas to $> 7000 \mu\text{g/g}$ at the downstream sites of Rivers Aire (Owens & Walling, 2002). These elevated TP values reflect the input from point sources such as sewage treatment works (STWs) and combined sewer overflows (CSOs) (Owens & Walling, 2002). Although the influent to STWs is treated before discharged into rivers as effluents, sometimes untreated sewage is discharged directly into the rivers during rainfall events via CSOs and STW bypass channel (Owens & Walling, 2002). Owens & Walling (2002) reported that TP content during low flow condition in July 1999, showed the values of 5622 $\mu\text{g/g}$ at upstream and 8765 $\mu\text{g/g}$ at downstream sites whereas, during high flow condition in December 1999, the values at upstream site was 2523 $\mu\text{g/g}$ and downstream site was 4349 $\mu\text{g/g}$ in River Aire (Owens & Walling, 2002). The increase in the TP content of the suspended sediment from the upstream to the downstream in both low and high flow condition, indicates that the effluent from the STW is one of the main sources of the TP content in suspended sediment (Owens & Walling, 2002).

2.5.4 Organic Matter and Organic Carbon

Organic matter is the vast array of carbon compounds in soil. Soil organic matter (SOM) is the plant and animal residues organic matter component of soil. Organic matter mainly come from crop residue, green manure, livestock manure, sewage sludge (human wastes), and organic wastes (Lewandowski, 2017). According to a research done by Boyes and Elliott (2006), the organic load entering Humber Estuary, England in 2001 from industry, sewage, natural vegetation and other diffuse sources was approximately 28,000 tonnes C yr⁻¹. Organic matter is measured as part of the dry solids sediment (Winterwerp & Kesteren, 2004). The loss of weight of sediment from heating and burning is the measurement for the organic fraction (OM) (Winterwerp & Kesteren, 2004). A study conducted by Nagarajan *et al.* (2015) at the spit of the Baram River mouth reported that organic matter in the Baram River region varied from 4.1 to 15.5 %. The high values found in the mentioned region is the result of flooding of river water discharging heavy organic matter during various rainfall events, where organic matter eroded from streams and forest area (Nagarajan *et al.*, 2015).

Besides, total organic carbon (TOC) is another parameter to quantify organic matter of sediment, the ratio between TOC and OM is approximately 2.5 (Winterwerp & Kesteren, 2004). A study done by Nasnolkar *et al.*, (1996) observed that peak values of organic carbon could be attributed to the influx of land runoff containing considerable amount of organic matter. The increase in sediment phosphate is due to the dead organic matter settling from upstream (Nasnolkar *et al.*, 1996). In addition, organic manures result in increased soil organic matter content also increase the source of available carbon, thus, soil microbial activity also increased (Haynes & Naidu, 1998).

CHAPTER 3

WATER QUALITY

3.1 Introduction

Rivers are essential for water supply, natural resources, and to sustain habitats for flora and fauna. It also provides support to fisheries industry and the development of hydropower dams (Salih *et al.*, 2013). River water supply is for agricultural, domestic and industrial needs. The increasing demand for water resources as a result of an increasing population has placed pressure on the water quality (Kannel *et al.*, 2008). Human activities such as deforestation, agricultural practices, chemical disturbance, urbanization, industrialization, and dams and reservoirs had altered global water system (Falkenmark & Widstrand, 1992). Surface waters can be contaminated by human activities in two ways which include point sources, such as sewage treatment discharge and storm-water run off; and non-point sources such as runoff from urban and agricultural areas (Sliva & Williams, 2001). Major water pollution sources include domestic sewage, industrial wastewater, livestock discharge, and urban and agricultural runoff (Park & Lee, 2002). Soil erosion associated with deforestation and land use changes such as re-plantation are the major activities at the upstream of Baram River (Nagarajan *et al.*, 2015) may have degraded the water quality of the river. Therefore, it is important to determine the water quality of Baram River, Sarawak, Malaysia, in order to protect and restore the rivers from anthropogenic activities. The objectives of this study were to determine the water quality of the main Baram River and its tributaries, the effect of rainfall events on the water quality of the main Baram River and its tributaries and the loadings of pollutants from the tributaries into the Baram River.

3.2 Materials and Methods

3.2.1 Study Area and Sampling Stations

This study was conducted at the upper Baram River, above Long Lama, Sarawak. Baram River is one of the major rivers in the Sarawak state, Malaysia. The total length of the Baram river is approximately 401 km (DID, 2017). It has a catchment area of approximately 22,800 km² and it discharges an estimated average of 1,590 m³/s of water and 2.4×10^{10} kg/year of sediment load (Straub & Mohrig, 2009). The mouth of Baram River, Sarawak is located 29.1 km from the city of Miri.

A total of 31 stations were selected for this study. These stations were chosen because of the anthropogenic activities nearby. Figure 5 shows the sampling stations (Station 1 to 31) located at the Upper Baram River, Sarawak. The downstream section is approximately 250 km away, while, midstream section is approximately 350 km away and the upstream section is approximately 400 km away from the mouth of the Baram River. The upstream section of Baram River and its tributaries were covered from Lio Mato to Moh River, the midstream section of Baram River were covered from Long Apu to Patah River and the downstream section of Baram River and its tributaries were covered from Kahah River to Btg Kemenyeh River. The nearest sampling station to Miri city was located approximately 180.2 km away. The total main Baram river distance covered in the present study was 171.9 km from station 1 to station 27.

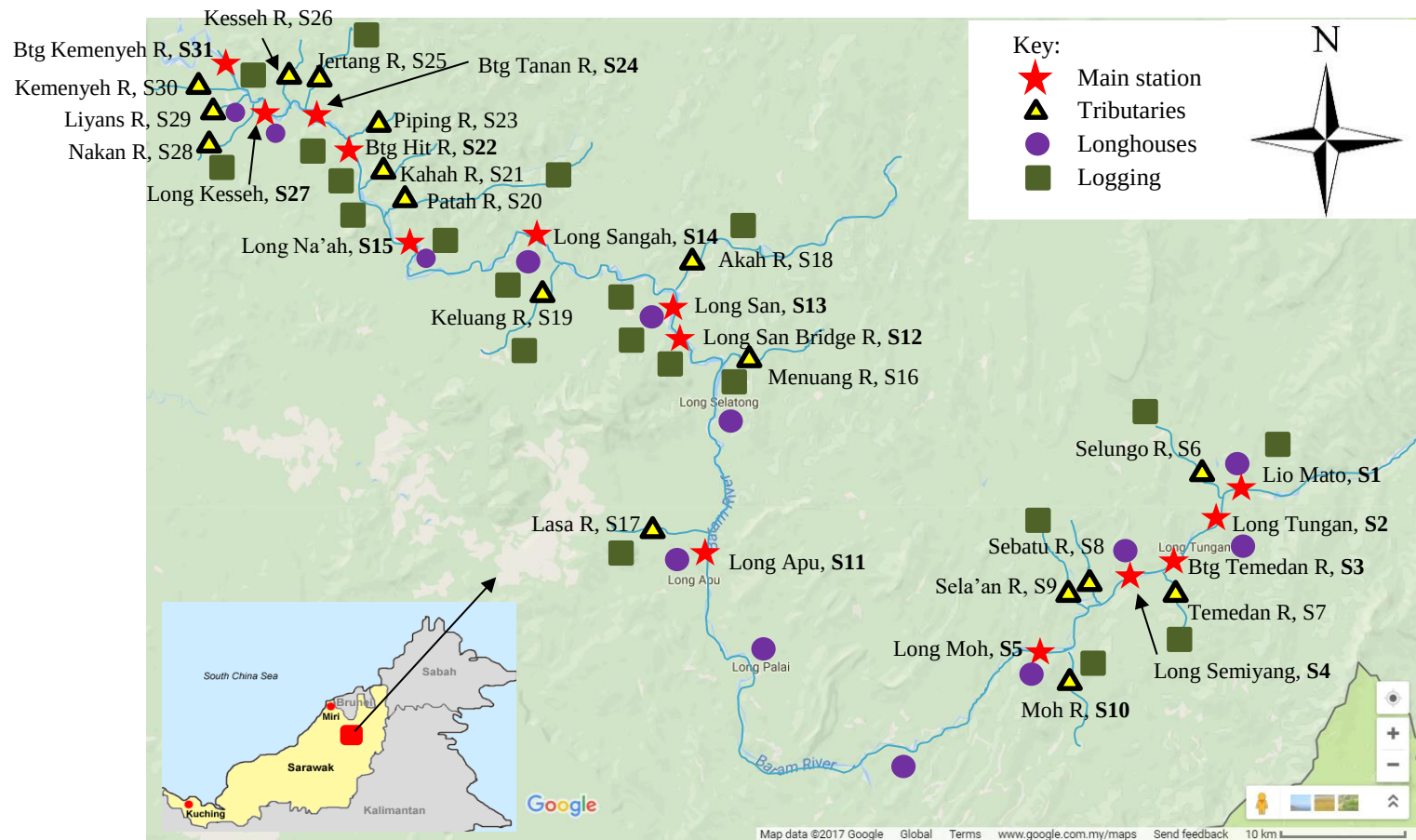


Figure 5: Map of the sampling stations at Baram River, Sarawak.

3.2.2 Sampling Regime

One trip was made to stations 1 to 30 from upstream to downstream section of the Baram River, Sarawak. Besides, two additional trips were made to the 10 stations (stations 15, 20, 22, 23, 24, 25, 26, 27, 28, and 31) at the downstream area, to study the effect of rainy season. Table 1 shows the global positioning system (GPS) location, sampling dates and time and the descriptions of all the stations selected at the Baram River and its tributaries. Table 2 shows the sampling dates and descriptions of all the trips at the Baram River.

Table 1: Sampling stations with GPS location, sampling date and time and the station's descriptions from upstream to downstream area of Baram River, Sarawak.

Station	Location	GPS	Date and Time	Descriptions
1	Lio Mato ~ Main river, 0.5 km downstream of longhouses, Lio Mato	N 03°10'10.8" E 115°11'47.6"	30 Jul 2015 1626	• Longhouses • Logging Activities
2	Long Tungan ~ Main river, 0.5 km downstream of longhouses, Long Tungan	N 03°09'34.0" E 115°10'51.0"	30 Jul 2015 1515	Longhouses
3	Btg Temedan River ~ Main river, 0.2 km downstream of the estuary of Temendan River	N 03°07'21.8" E 115°09'10.5"	30 Jul 2015 1440	Longhouses
4	Long Semiyang ~ Main river, 0.5 km downstream of longhouses, Long Semiyang	N 03°06'54.0" E 115°07'21.8"	30 Jul 2015 1357	Longhouses
5	Long Moh ~ Main river, 0.5 km downstream of longhouses, Long Moh	N 03°03'37.5" E 115°03'23.3"	30 Jul 2015 1026	• Open burning for re-plantation • Longhouses
6	Selungo River ~ Tributary, 0.2 km from the confluence	N 03°10'15.0" E 115°11'46.7"	29 Jul 2015 1618	Logging activities
7	Temedan River ~ Tributary, 0.2 km from the confluence	N 03°06'50.0" E 115°08'52.2"	29 Jul 2015 1505	Logging activities
8	Sebatu River ~ Tributary, 0.3 km from the confluence	N 03°05'50.6" E 115°05'46.3"	29 Jul 2015 1401	
9	Sela'an River ~ Tributary, 0.2 km from the confluence ~ Logging activities	N 03°05'50.5" E 115°04'52.7"	29 Jul 2015 1259	Logging activities
10	Moh River ~ Tributary, 0.5 km from the confluence	N 03°02'34.1" E 115°04'35.9"	29 Jul 2015 1121	
11	Long Apu ~ Main river, 0.5 km downstream of longhouses, Long Apu	N 03°08'23.6" E 114°48'52.7"	04 Sep 2015 1509	Longhouses

Table 1 continued

12	Long San Bridge ~ Main river, 0.2 km upstream of Long San Bridge	N 03°16'56.6" E 114°47'53.1"	04 Sep 2015 1733	
13	Long San ~ Main river, 0.5 km downstream of longhouses, Long San	N 03°17'49.6" E 114°47'08.1"	04 Sep 2015 1254	• Longhouses • Logging activities
14	Long Sangah ~ Main river, 0.5 km downstream of longhouses, Long Sangah	N 03°21'19.0" E 114°41'31.5"	04 Sep 2015 1104	• Longhouses • Logging activities
15	Long Naha'a ~ Main river, 0.5 km downstream of longhouses, Long Naha'a	N03°19'50.8" E114°35'43.1"	04 Sep 2015 0951 13 Jan 2016 0932 14 Jan 2016 1004	• Longhouses • Logging activities
16	Menuang River ~ Tributary, 0.5 km from the confluence	N 03°16'19.1" E 114°49'22.4"	04 Sep 2015 1656	Logging activities
17	Lasa River ~ Tributary, 0.5 km from the confluence	N 03°05'40.8" E 114°48'49.2"	04 Sep 2015 1541	Logging activities
18	Akah River ~ Tributary, 0.5 km from the confluence	N 03°19'11.3" E 114°47'32.7"	03 Sep 2015 1446	• Residential area upstream • Logging activities
19	Keluang River ~ Tributary, 0.5 km from the confluence	N 03°19'58.6" E 114°42'21.8"	03 Sep 2015 1300	Logging activities
20	Patah River ~ Tributary, 0.5 km from the confluence	N03°21'02.9" E114°36'22.3"	03 Sep 2015 1042 13 Jan 2016 1010 14 Mar 2016 1033	Logging activities
21	Kahah River ~ Tributary, 0.2 km from the confluence	N 03°23'12.9" E 114°34'05.7"	22 Jan 2015 0900	Logging activities
22	Btg Hit River ~ Main river, 0.2 km downstream of the estuary of Hit River	N 03°23'08.4" E 114°33'35.8"	22 Jan 2015 0945 13 Jan 2016 1048 14 Mar 2016 1105	Logging activities
23	Piping River ~ Tributary, 0.5 km from the confluence	N 03°24'47.4" E 114°33'39.0"	22 Jan 2015 1025 13 Jan 2016 1123 14 Mar 2016 1131	Logging activities
24	Btg Tanan River ~ Main river, 0.2 km downstream of the estuary of Tanan River	N 03°25'45.9" E 114°33'00.5"	21 Jan 2015 1030 13 Jan 2016 1154 14 Mar 2016 1150	Logging activities

Table 1 continued

25	Jertang River ~ Tributary, 0.2 km from the confluence	N03°26'19.3" E114°32'28.3"	21 Jan 2015 1108 13 Jan 2016 1219 14 Mar 2016 1602	Logging activities
26	Kesseh River ~ Tributary, 0.3 km from the confluence	N 03°27'26.2" E 114°30'44.5"	21 Jan 2015 1145 14 Jan 2016 0818 13 Mar 2016 1529	Longhouses, 50 m upstream of the Long Kesseh
27	Long Kesseh ~ Main river, next to longhouses, Long Kesseh	N 03°27'11.3" E 114°30'29.4"	21 Jan 2015 1220 14 Jan 2016 0844 13 Mar 2016 1507	Longhouses
28	Nakan River ~ Tributary, 0.3 km from the confluence, next to Long Nakan	N03°26'29.6" E114°29'20.6"	21 Jan 2015 1415 14 Jan 2016 0915 13 Mar 2016 1433	• Logging activities • Longhouses • Oil palm plantation
29	Liyans River ~ Tributary, 0.1 km from the confluence	N 03°27'07.8" E 114°29'15.3"	21 Jan 2015 1452	
30	Kemenyeh River ~ Tributary, 0.2 km from the confluence	N 03°27'46.7" E 114°28'29.4"	21 Jan 2015 1115	Logging activities
31	Btg Kemenyeh River ~ Main river, 0.2 km downstream of the estuary of Kemenyeh River	N03°27'54.7" E114°28'18.2"	14 Jan 2016 1001 13 Mar 2016 1349	

Table 2: Sampling dates at each area and the description of the conditions during each trip.

Trip	Sampling Area	Sampling date and Descriptions	
1	Upstream area, (Stations 1-10)	29 Jul 2015	30 Jul 2015
		Lio Mato downstream area (Stations 6 – 10), • Cloudy and windy • Water level- moderate (> 1.0 m) • Rained for a week before sampling (Ranged from 1.2 – 40.6 mm) • Rained on the night before sampling (11.2 mm)	Lio Mato upstream area (Stations 1 – 5), • Cloudy and windy • Small rain • Water level- moderate • Rained for a week before sampling (Ranged from 1.2 – 40.6 mm)
2	Midstream area, (Stations 11-20)	03 Sep 2016	04 Sep 2016
		Long San downstream area (Stations 18 – 20), • Sunny and windy • Water level- high (> 2.0 m) • Rained during midnight before sampling (24.4 mm)	Long San upstream area (Stations 11 – 17), • Sunny and windy • Water level- high • Rained on the day before sampling (24.4 mm)
3	Downstream area, (Stations 21-30)	21 Jan 2015	22 Jan 2015
		Long Kesseh downstream area (Stations 24 – 29), • Cloudy and windy • Water level- very high (>5.0 m) • Rained on the night before sampling (47.4 mm) • Rained during midnight before sampling (13.6 mm)	Long Kesseh up and downstream area (Stations 21 – 23, 30), • Cloudy and windy • Water level- very high • Rained on the day before sampling (13.6 mm) • Rained during midnight before sampling (32.8 mm)
4	Downstream area (Stations 15, 20, 22, 23, 24, 25, 26, 27, 28, and 31)	13 Jan 2016	14 Jan 2016
		Long Kesseh upstream area (Stations 15, 20, 22 – 25), • Sunny and windy • Water level- high • No rain for a week before sampling (5th-8th Jan, 2016 shows 0.0 mm) • Small or no rain during sampling (12nd-19th Jan, 2016 shows 0.0 mm)	Long Kesseh upstream area (Stations 26 – 28, 31), • Sunny • Water level- low (<1.0 m) • No rain for a week before sampling (5th-8th Jan, 2016 shows 0.0 mm) • Small or no rain during sampling (12nd-19th Jan, 2016 shows 0.0 mm)

Table 2 continued

		13 Mar 2016	14 Mar 2016
		Long Kesseh downstream area (Stations 25 – 28, 31), • Sunny • Water level- high • No rain for a week before sampling (8th-10th Mar, 2016 shows 0.0 mm) • No rain on the day before sampling (0.0 mm)	Long Kesseh upstream area (Stations 15, 20, 22 – 24), • Sunny and windy • Water level- low • No rain for a week before sampling (8th-10th Mar, 2016 shows 0.0 mm) • Small or no rain before sampling (12nd-14th Mar, 2016 shows 0.0 mm)

3.2.3 Preparation and Sample Collection

All sampling bottles were made of polyethylene (PE). The sampling bottles were soaked overnight in nitric acid (HNO₃), 10 % or hydrochloric acid (HCl), 10 % solution. Then, the bottles were rinsed several times with tap water followed by distilled water. Besides, biochemical oxygen demand (BOD) glass bottles were rinsed several times with tap water and followed by distilled water. All the sampling bottles were rinsed with river water before taking the subsurface water at the side of the river as the sample for analyses. Triplicate water samples were collected from the subsurface of the river. Besides, samples in BOD glass bottles were wrapped with aluminium foil and newspaper immediately in the field to prevent the exposure of the samples to sunlight after measuring the initial dissolved oxygen (DO). Concentrated sulphuric acid (H₂SO₄), 96 % (2 mL) was added to each 250 mL of samples as a preservative for the analyses of chemical oxygen demand (COD), total phosphorus (TP), organic-nitrogen (Org-N), and ammonia-nitrogen (NH₃-N). These analyses were done within seven days after the sampling in the field.

On the other hand, preservative was not added to the samples that were used for nitrite-nitrogen ($\text{NO}_2\text{-N}$), nitrate-nitrogen ($\text{NO}_3\text{-N}$), total suspended solids (TSS), five days biochemical oxygen demand (BOD_5), and chlorophyll-*a* (Chl-*a*) analyses. Filtration of TSS and Chl-*a* analyses were done within nine hours after the sampling in the field. The analyses of $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ were done within twelve hours after the sampling. In addition, a piece of 47 mm diameter with 0.7 μm pore size (Whatman, GF/F) and 1.0 μm pore size (Whatman, GF/B) of glass microfiber filter paper was prepared and used for the filtration process of Chl-*a* and TSS analyses in the field respectively. The 0.7 μm pore size of filter paper with residue was stored in the dark and cooled to 4 °C after samples filtration process in subdued light. The filtrates that passed through the 0.7 μm pore size of glass microfiber filter paper (Whatman, GF/F) were used for the analyses of $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the field. The 1.0 μm pore size of filter paper with residue was stored in the dark and kept in silica gel.

3.2.4 Meteorological Data

The total daily rainfall data for each month from January of 2015 to July of 2016 were obtained from Malaysia Meteorology department in Kuching, Sarawak. The nearest meteorological data was collected at the Miri International Airport station with a Latitude of 04 Deg. 20' N and Longitude of 113 Deg. 59' E.

3.2.5 Field Measurement (Hydro-geometric Data)

3.2.5.1 Geometric Characteristics

The geometric and hydraulic characteristics were studied at every station from stations 1 to 31. The rivers were only accessed one time per trip with three replicates measured. The width of the river was measured by using a range finder (Bushnell, Elite 1500) and the depth of the river was measured at a transect (roughly every 5 m for the main river and every 1 m for a tributary) across the river with a depth finder (Hondex, PS-7 LCD Digital Sounder). The width and depth determined were applied in a point estimate method to calculate the cross-sectional area, A_c , of the river (Chapra, 1997).

The cross-sectional area of the river was calculated by using the area of a triangle for the segment near the river bank on both sides of the river and the area of a trapezium for other segments across the river, and then the areas were added as illustrated in Figure 6. The length of the river was estimated by using Google Earth. Once the coordinate was measured using GPS (Garmin, 76S), the length of a particular segment was estimated. Then, the mean volume of that segment was calculated (Chapra, 1997).

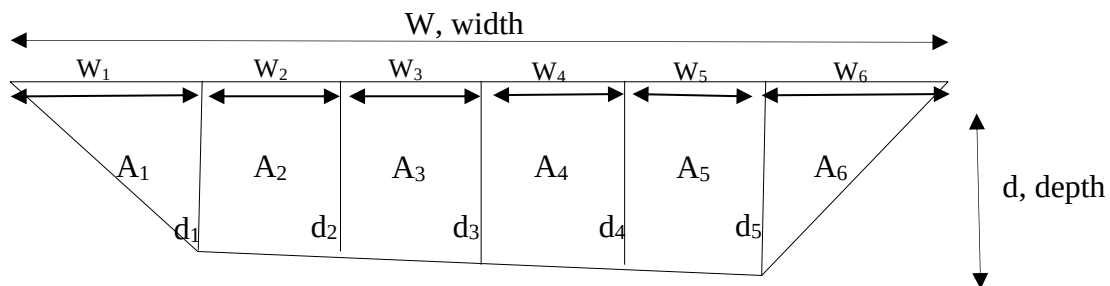


Figure 6: Segmentation across the Baram River

The cross-sectional area of the river was calculated by using formula [1]:

$$A_c = A_1(0.5 \times d_1 \times W_1) + A_2[0.5 \times (d_1 + d_2) \times W_2] + A_3[0.5 \times (d_2 + d_3) \times W_3] + A_4[0.5 \times (d_3 + d_4) \times W_4] + A_5[0.5 \times (d_4 + d_5) \times W_5] + A_6(0.5 \times d_5 \times W_6) \quad [1]$$

where,

A_c = Cross-sectional area of the river, m^2 ,

W = Width measured across the river, m, and

d = Depth measured at roughly every 5 m for main river and 1 m for tributary, m

3.2.5.2 Hydraulic Characteristics

At each depth measurement, a corresponding velocity measurement was taken by using a flow meter (Geopacks, 2001). The flow of the river was calculated by using the formula [3] as illustrated in Figure 7.

The water velocity of the river at partition i was calculated by using formula [3]:

$$V_i = (0.000854C) + 0.05 \quad [3]$$

where,

V_i = Water velocity, m/s

C_i = Number of counts per minute

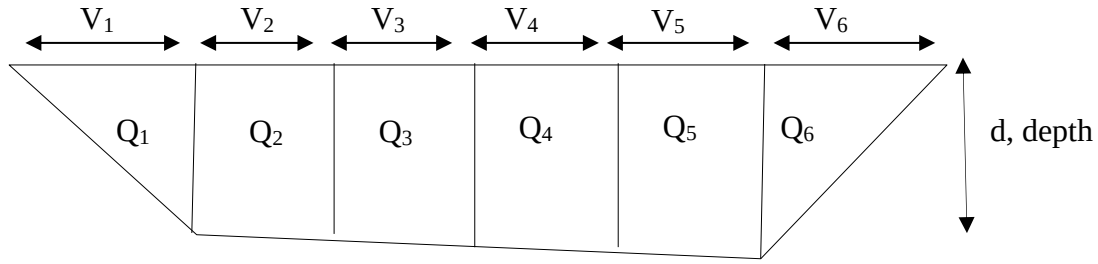


Figure 7: Segmentation across the Baram River

The flow or discharge of the river at partition i was calculated by using formula [4]:

$$Q_i = V_i \times A_i \quad [4]$$

where,

Q_i = Flow of the river at the partition i , m^3/s ,

V_i = Water velocity of the river at the partition i , m/s , and

A_i = Area of the river at the partition i , m^2

The total flow of the river was calculated by using formula [5]:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \quad [5]$$

where,

Q = Total flow of the river, m^3/s

3.2.6 *In-situ* Measurements

Seven *in-situ* measurements taken at the field were temperature (°C), DO (mg/L), DO saturation (%), pH, specific conductance ($\mu\text{S}/\text{cm}$), turbidity (NTU), and transparency (m). For the first trip to the downstream area, temperature and DO were measured by using a YSI Pro 20 DO meter; specific conductance was measured by using a conductivity meter (EUTECH INSTRUMENTS, Cyberscan CON 11); pH value was measured by using a pH meter (Trans Instruments, TI9000 WalkLab) and turbidity was measured by using a turbidity meter (Lutron, TU 2016).

In subsequent trips, a multi-parameter YSI 6920 V2-2 water quality sonde (YSI, 6920V2-01) was used to measure temperature (°C), DO (mg/L), DO saturation (%), pH, specific conductance ($\mu\text{S}/\text{cm}$), and turbidity (NTU). Transparency (m) was measured with a Secchi disk and a measuring tape. Global positioning system (GPS) location (Garmin, GPS map 62s), weather and surrounding conditions were also recorded in a field book.

3.2.7 *Ex-situ* Analyses

$\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, and TS were analysed approximately eight hours after the field trips at the camp site by using Hach methods. The concentrations were determined by using DR 900 (Hach, 2015) in the field. Another *ex-situ* analyses include, Chl-*a*, TSS, BOD_5 test, COD, Org-N, $\text{NH}_3\text{-N}$, and TP were analysed by using Standard Methods for the Examination of Water and Wastewater (APHA, 2005) in the environmental lab.

3.2.7.1 Total Suspended Solids (TSS)

The analysis was carried out approximately 10 hours after the collection of water samples following the 2540D of Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

3.2.7.1.1 Preparation of Filter Papers

A piece of 47 mm diameter with 1.0 μm pore size of glass microfiber filter paper (Whatman, GF/B) was dried in an oven at 105 °C for two hours and cooled in a desiccator. Then, the filter paper was stored in a folded envelope of aluminium foil before the filtration process. The initial weight of the filter paper was taken by using a weighing machine (A&D Company, FX-300i). Next, the filter paper was used for the filtration process of TSS after sample collection.

3.2.7.1.2 Filtration process

One litre of the sample was filtered through the filter paper with suction provided by a vacuum pump (GAST, DOA-P504-BN). The volume of the sample to be filtered mostly depended on the duration of the filtration process. If the complete filtration took more than 10 minutes, the sample volume was decreased (APHA, 2005). After the filtration process, the filter paper with aluminium foil was dried overnight in an oven at 105 °C and cooled in a desiccator. Drying and weighing processes were repeated until a constant weight of the filter paper was recorded. Then, the constant weight of the filter paper was recorded as the final weight.

The amount of TSS present in the sample was calculated by using formula [6]:

$$TSS = \frac{W_f - W_i}{V} \times 1000 \quad [6]$$

where,

TSS = Total suspended solids, mg/L,

W_f = Final weight of filter paper, g,

W_i = Initial weight of filter paper, g, and

V = Filtered sample volume, L

3.2.7.2 Chlorophyll-*a* (Chl-*a*)

All the green plants contain Chl-*a*, which constitutes approximately 1 to 2 % of the dry weight of planktonic algae (APHA, 2005). The filtration was carried out approximately nine hours after the collection of water samples following the 10200H method of Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

3.2.7.2.1 Preparation of Filter Papers

A piece of 47 mm diameter with 0.7 µm pore size of glass microfiber filter paper (Whatman, GF/F) was dried in an oven at 105 °C for two hours and cooled in a desiccator. Then, the filter paper was stored in a folded envelope of aluminium foil before the filtration process.

3.2.7.2.2 Pigment Extraction

Water sample was stored at around 4 °C and protected from exposure to sunlight before undergoing filtration. The extraction of Chl-*a* was conducted in subdued light to avoid degradation (APHA, 2005). The filter paper with residue on it was wrapped with aluminium foil and stored at around 4 °C before analysis.

The filter paper with sample on it was placed in a tissue grinder (ceramic mortar) and 2 to 3 mL of 90 % aqueous acetone solution was added. The sample was ground into smaller pieces. Then, the sample was transferred to a screw-capped, 15 mL in volume of centrifuge tube and the sample was adjusted to a total volume of 10 mL by adding 90 % aqueous acetone solution. The centrifuge tube was macerated at 2000 rpm for 20 minutes. The centrifuge tube was wrapped with aluminium foil to prevent the exposure of sunlight. The sample was steeped for at least two hours at around 4 °C in the dark. Then, the sample was analyzed by using UV-VIS spectrophotometer (JASCO, V630) at 630, 647, 664, and 750 nm. The absorbance was recorded.

The amount of Chl-*a* present in the sample was calculated by using Equation [7] & [8]:

$$C_a = 11.85(abs_{664} - abs_{750}) - 1.54(abs_{647} - abs_{750}) - 0.08(abs_{630} - abs_{750})$$

[7]

$$Chl - a = \frac{C_a \times Extracted Vol}{Sample Vol}$$

[8]

where,

C_a = Concentration of chlorophyll-*a* in the sample, mg/L,

Chl-*a* = Chlorophyll-*a* concentration, mg/m³,

Extract Vol = Volume extracted from the sample, 0.01 L, and

Sample Vol = Volume of sample filtered, m³

3.2.7.3 Five Days Biochemical Oxygen Demand (BOD₅) Test

This test was conducted following the 5210B of Standard Methods for the Examination of Water and Wastewater (APHA, 2005). BOD glass bottle was rinsed thoroughly with tap water followed by distilled water. Sample was transferred to a suitable sized bottle for the preparation of dilution. Sample was shaken by mixing 500 mL of sample with 500 mL of distilled water which had a dilution factor of 1:1. Then, the sample was transferred into a BOD glass bottle with a ground-glass stopper. The volume of the BOD glass bottle used was 300 mL for the first trip and 60 mL for the second, third, forth, and fifth trips. The initial reading of DO was recorded. Then, the glass bottle was wrapped with aluminum foil and newspaper to prevent light from entering the bottle to prevent the photosynthetic production of DO. Then, the BOD bottle was stored in the dark and the sample was incubated at around 20 ± 1 °C. The final reading of DO was measured after five days incubation period.

The BOD₅ concentration in the sample was calculated by using formula [9]:

$$BOD_5 = \frac{D_1 - D_2}{p} \quad [9]$$

where,

BOD_5 = Five day biochemical oxygen demand, mg/L,

D_1 = DO of diluted sample immediately after shaking, mg/L,

D_2 = DO of diluted sample after 5 days incubation at 20 ± 1 °C, mg/L, and

P = Decimal volumetric fraction of sample used (0.5 L/1.0 L)

3.2.7.4 Chemical Oxygen Demand (COD) Test

COD test was conducted by following the closed reflux; titrimetric method of the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Culture tube was washed and soaked overnight in 20 % H_2SO_4 solution before use to prevent contamination. After that, the tube was rinsed with tap water followed by distilled water. A block digester (HANNA, C9800 Reactor) and a block heater (Stuart, SBH200D) were preheated for 30 minutes at 150 °C. Next, 2.5 mL of sample was placed into the culture tube and 1.5 ml of digestion solution was added. Then, 3.5 mL of H_2SO_4 reagent was carefully run down inside of the vessel so that an acid layer was formed under the sample digestion solution layer. The tube was capped tightly and inverted several times to mix completely. Then, the tube was placed in the block digester and refluxed for two hours. After two hours, the tube was cooled to room temperature.

A blank was prepared by adding 1.5 mL digestion solution and 3.5 mL H₂SO₄ reagent into the culture tube with a 2.5 mL distilled water. Then, the tube was capped tightly and inverted several times to mix completely. The blank was heated together with the sample. After that, the tube was cooled to room temperature. The sample was transferred into a volumetric flask and two drops of ferroin indicator was added. Then, the sample was titrated with standardized 0.025 M ferrous ammonium sulfate (FAS) solution. The end point of the sample was a sharp colour change from blue-green to reddish brown. The FAS solution was standardized daily by adding 5.0 mL of digestion solution to 10.0 mL of distilled water in a volumetric flask. Then, two drops of ferroin indicator was added into the flask. The solution was titrated against the 0.025 M FAS solution. The end point of the solution was a sharp colour change from blue-green to reddish brown. The volume of 0.025 M FAS titrated was recorded. The molarity of FAS solution must fall in between 0.024 M to 0.026 M.

The molarity of FAS solution was verified by using formula [10]:

$$M = \frac{5.0 \text{ mL } K_2Cr_2O_7 \text{ titrated}}{\text{Vol FAS used}} \times 0.1 \quad [10]$$

The COD concentration was calculated by using formula [11]:

$$COD = \frac{(A-B) \times M \times 8000}{\text{Sample Vol}} \quad [11]$$

where,

M = Molarity of FAS solution, M,

COD = chemical oxygen demand concentration, mg/L

A = volume of FAS used for blank, mL

B = volume of FAS used for sample, mL

8000 = milliequivalent weight of oxygen x 1000 mL/L

3.2.7.5 Total Phosphorus, Unfiltered (TP)

Total phosphorus was conducted following the H₂SO₄-HNO₃ digestion method followed by ascorbic acid method according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

3.2.7.5.1 Digestion Process

A sample volume of 50 mL was transferred into a micro-Kjeldahl flask. Then, 1 mL of concentrated H₂SO₄ and 5 mL of concentrated HNO₃ were added. Then, the flask was placed in a heating digester (VELP SCIENTIFICA, DKL Heating Digester) and the sample was digested at 200 °C until the volume reduced to about 1 mL. The digestion of the sample was continued until the solution becomes colourless to remove HNO₃. After that, the solution was cooled and 20 mL of distilled water and one drop of phenolphthalein indicator solution were added. Then, 1 N of NaOH solution was added into the sample to produce a faint pink tinge. Then, the sample volume was marked up to 100 mL with distilled water.

3.2.7.5.2 Ascorbic acid Method

A sample volume of 50 mL was pipetted into a clean and dry 125 mL Erlenmeyer flask and one drop of phenolphthalein indicator was added. Then, 8 mL combined reagent was added and mixed thoroughly. After waiting for 10 minutes of the reaction time, the sample was analyzed by using UV-VIS spectrophotometer (JASCO, V630) at 880 nm within 30 minutes. The absorbance was recorded.

3.2.7.5.3 Calibration Step

Firstly, anhydrous potassium dihydrogen phosphate (KH_2PO_4) was dried in an oven at 105 °C for an hour and cooled in a desiccator. Then, 0.2195 g of dried KH_2PO_4 was weighed. Stock KH_2PO_4 solution was prepared by dissolving the dried KH_2PO_4 in distilled water and diluted to 1.0 L in a standard flask (1.0 mL = 50.0 μg P). Secondly, intermediate KH_2PO_4 solution was prepared by diluting 50.0 mL of the stock solution to 1.0 L (1.0 mL = 2.5 μg P). Then, different concentrations of P was prepared by using the volume of 0.0, 5.0, 10.0, 15.0, 20.0, 25.0 and 30.0 mL. The different concentrations were diluted to 250.0 mL in a standard flask. Next, the standard solutions were treated in the same manner as the sample. A reagent blank was carried out through all the steps of the procedure and necessary corrections were applied to the results.

The calibration equation for TP is shown in equation [12] and calibration curve is shown in Appendix 7:

$$\text{Abs} = 0.0006 \text{ Conc} - 0.0055 \quad [12]$$

3.2.7.6 Nitrite-Nitrogen (NO₂-N)

This analysis was conducted following the low range diazotization method, HACH 8507 Method (Hach, 2015). The concentration of the NO₂-N for the HACH DR 900 colorimeter is in the range of 0.005 to 0.350 mg/L. The sample with a volume of 10.0 mL was filled into a sample cell and contents of one NitriVer 3 Nitrite reagent powder pillow were added. Then, the cell was capped and shaken for three minutes to allow the powder pillow to dissolve. After waiting for 20 minutes of the reaction time, a pink colour developed which indicated the presence of nitrite. Distilled water was used as a blank followed by the same procedures as the sample. The blank and sample concentrations were by using HACH DR 900 colorimeter. The concentration of the NO₂-N was recorded.

3.2.7.7 Nitrate-Nitrogen (NO₃-N)

The NO₃-N analysis was conducted following the cadmium reduction method, HACH 8192 Method (Hach, 2015). The concentration of the NO₃-N for the HACH DR 900 colorimeter is in the range of 0.01 to 0.50 mg/L. The sample with a volume of 15.0 mL was filled into a sample cell and contents of NitraVer 6 Nitrate powder pillow were added. Then, the cell was capped and shaken vigorously for three minutes followed by waiting period of two minutes of the reaction time. Then, 10.0 mL of sample was transferred into another sample cell and contents of one NitriVer 3 Nitrite powder pillow were added. The cell was shaken gently for 30 seconds followed by waiting period of 15 minutes of the reaction time. A pink colour developed which indicated the presence of nitrate. Distilled water was used as a blank followed by the same procedures as sample. The blank and sample were analyzed by using HACH DR 900 colorimeter. The concentration of NO₃-N was recorded.

The NO₃-N concentration was calculated by using formula [13],

$$NO_3 - N = (NO_3 - N)_{DR900} - (NO_2 - N)_{DR900} \quad [13]$$

where,

NO₃-N = Concentration of nitrate-nitrogen, mg/L

NO₃-N_{DR900} = Concentration of nitrate-nitrogen obtained from DR900, mg/L, and

NO₂-N_{DR900} = Concentration of nitrite-nitrogen obtained from DR900, mg/L

3.2.7.8 Ammonia-Nitrogen (NH₃-N)

NH₃-N analysis was conducted following the preliminary distillation step in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005) and the determination of the presence of ammonia by Nessler's method, HACH 8038 Method (Hach, 2015).

3.2.7.8.1 Preliminary Distillation Step

During distillation process, a volume of 100.0 mL of sample was transferred into a distillation flask and 10.0 mL of borate buffer solution was added. The solution was adjusted to pH 9.5 by using 1 N sodium hydroxide (NaOH) solution. Then, the flask was placed in a semi-automatic distillation unit (VELP SCIENTIFICA, UDK139). The timer was set for two and half minutes. Then, the distillate was measured and collected in a 250.0 mL Erlenmeyer flask which contained 10.0 mL of boric acid (H₃BO₃) solution. The collection tube was placed into the H₃BO₃ solution to prevent the loss of ammonia gas.

3.2.7.8.2 Nessler's Method

Then, the pH of the sample was adjusted to pH 7 by using 1 N NaOH and marked up to 100.0 mL with ammonia-free water. After that, three drops of mineral stabilizer, three drops of polyvinyl alcohol dispersing agent and 1.0 mL of Nessler's reagent were added into a 25.0 mL of sample. The sample was analyzed by using UV-VIS spectrophotometer (JASCO, V630) at 425 nm. The absorbance was recorded.

3.2.7.8.3 Calibration Step

Firstly, anhydrous ammonium chloride (NH_4Cl) was dried in an oven at 105 °C for an hour and cooled in a desiccator. Then, 3.819 g of dried NH_4Cl was weighed. Stock NH_4Cl solution was prepared by dissolving the dried anhydrous NH_4Cl in distilled water and diluted to 1.0 L in a standard flask (1.0 mL=1.00 mg N). Secondly, intermediate NH_4Cl was prepared by diluting 25.0 mL of the stock solution to 1.0 L (1.0 mL=0.025 mg N). Then, different concentrations of N were prepared by using the volume of 0.0, 2.0, 4.0, 6.0, 8.0 and 10.0 mL. The different concentrations were diluted to 250.0 mL in a standard flask. Next, the standard solutions were analysed in the same manner as the sample. A reagent blank was carried out through all the steps of the procedure and necessary corrections were applied to the results.

The calibration equation for $\text{NH}_3\text{-N}$ is shown in equation [14] and calibration curve is shown in Appendix 8:

$$\text{Abs} = 0.2286 \text{ Conc} - 0.02014 \quad [14]$$

3.2.7.9 Organic-Nitrogen (Org-N)

Kjeldahl nitrogen is the sum of Org-N and $\text{NH}_3\text{-N}$ (APHA, 2005). The Org-N was conducted following the 4500- N_{org} B, macro-Kjeldahl method as stated in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

3.2.7.9.1 Digestion Process

A sample volume of 50 mL was transferred into the Erlenmeyer flask and 5 mL of borate buffer was added. The pH was adjusted to pH 9.5 with 6 N NaOH. Then, the sample was transferred into a Kjeldahl flask and 5 mL of digestion reagent was added. Then, the flask was placed in a heating digester (VELP SCIENTIFICA, DKL Heating Digester) and the sample was digested at 250 °C until the volume reduced to about 30 mL. When a copious white fume was observed, the digestion of the sample was continued for another additional 30 minutes. The flask was cooled and topped up to 30 mL by using ammonia-free water. Then, 5 mL of sodium hydroxide-sodium thiosulphate reagent ($\text{NaOH-Na}_2\text{S}_2\text{O}_3$) solution was added.

3.2.7.9.2 Distillation Process

Then, the flask was placed in a semi-automatic distillation unit (VELP SCIENTIFICA, UDK139). The timer was set for two and half minutes. Then, the distillate was measured and collected in a 250 mL Erlenmeyer flask which contained 5 mL of H_3BO_3 solution. The collection tube was placed into the H_3BO_3 solution to prevent the loss of ammonia gas.

3.2.7.9.3 Nessler's Method

The sample was adjusted to pH 7 by using 1 N of NaOH. A sample volume of 25 mL was placed into a culture tube and three drops of mineral stabilizer, three drops of polyvinyl alcohol dispersing agent and 1 mL of Nessler's reagent were added. The tube was inverted to mix completely. The sample was analysed by using UV-VIS spectrophotometer (JASCO, V630) at 425 nm.

3.2.7.9.4 Calibration Step

Firstly, glutamic acid ($\text{C}_3\text{H}_5\text{NH}_2(\text{COOH})_2$) powder was dried in an oven at 105 °C for 24 hours and cooled in a desiccator. Then, 1.051 g of dried $\text{C}_3\text{H}_5\text{NH}_2(\text{COOH})_2$ was weighed. Stock $\text{C}_3\text{H}_5\text{NH}_2(\text{COOH})_2$ solution was prepared by dissolving the dried $\text{C}_3\text{H}_5\text{NH}_2(\text{COOH})_2$ in distilled water and diluted to 1.0 L in a standard flask (1.0 mL=100.0 µg N). Secondly, intermediate $\text{C}_3\text{H}_5\text{NH}_2(\text{COOH})_2$ solution was prepared by diluting 25.0 mL of the stock solution to 1.0 L (1.0 mL=10.0 µg N). Then, different concentrations of N were prepared by using the volume of 0.0, 5.0, 10.0, 15.0, 20.0, 25.0 and 29.0 mL based on standard. The different concentrations were diluted to 100.0 mL in a standard flask. Next, the digestion check standards were analysed in the same manner as the sample. A reagent blank was carried out through all the steps of the procedure and necessary corrections were applied to the results.

The calibration equation for Org-N is shown in equation [15] and calibration curve is shown in Appendix 9:

$$\text{Abs} = 0.0691 \text{ Conc} - 0.0024 \quad [15]$$

3.2.8 Potential Pollutant Loads

Load may be defined as the mass of a substance that passes a particular point of a river in a specified amount of time (USEPA, 2017). Water discharge is defined as the volume of water that passes a cross-section of a river in a specified amount of time, while flow refers to the discharge rate, the instantaneous rate at which water passes a point (USEPA, 2017). The loading of the potential pollutant was calculated based on the sampling dates from 29th to 30th, Jul (upstream area), 03rd to 04th, Sep (midstream area) and 21st to 22nd, Jan (downstream area) in the year 2015.

The loading of the potential pollutant was calculated by using formula [16]:

$$L = c \times Q \times f \quad [16]$$

where,

L = Loading of the pollutant, kg/day

c = Concentration of the pollutant, mg/L

Q = Flow of the river, m³/s

f = Conversion unit (3600x24/1000)

3.2.9 Statistical Analyses

Significant difference of each parameter among stations was analysed by using one-way ANOVA at the 5 % significance level. Tukey's test was used for pairwise comparisons among the stations. Relationship between the parameters were analysed by using bivariate correlation and two tailed Pearson. Principal components analysis (PCA) was used to show the grouping of parameters. Two-way ANOVA was used to compare the mean values of the three trips carried at stations 22, 23, 24, 25, 26, 27, and 28 at the downstream area. Independent *t*-test was used to determine whether there was a statistically significant difference between the means in two unrelated groups, stations at the main river and the stations at tributaries. All data analyses were conducted by using IBM SPSS Statistics 20. National Water Quality Standards (NWQS) of Malaysia and Water Quality Index (WQI) were used to classify the status of water quality of Baram River.

3.3 Results and discussion

3.3.1 Meteorological Data

The meteorological data obtained from Malaysian Meteorology Department (Sarawak Branch) are shown in Appendices 17 and 18. Appendix 17 shows the records of daily total rainfall amount from Jan to Dec in the year 2015. Appendix 18 shows the records of the daily total rainfall amount from Jan to July in the year 2016. Based on Appendix 17, Jan 2015 (652.8 mm) recorded the highest daily total rainfall amount, whereas, Mar 2015 (15.8 mm) recorded the lowest daily total rainfall amount throughout the year. Meanwhile, low daily total rainfall amount was also recorded in Mar 2016 (85.8 mm).

3.3.2 Hydro-geometric Data

The hydro-geometric data of the main river stations were listed in Appendix 19, whilst, the tributaries at the upper Baram River, Sarawak were listed in Appendix 20. The locations of the stations are given in Table 1. The mean width of the stations at the main river ranged from 44 to 156 m, while, the tributaries ranged from 16 to 70 m. In addition, the mean depth of the stations at the main river was in the range of 0.8 to 14.1 m, while, the tributaries ranged from 0.2 to 5.2 m. Besides, the mean velocity of the stations at the main river ranged from 0.13 to 1.77 m/s, whilst, the tributaries is in the range of 0.06 to 1.76 m/s. The trend of the flow of the stations at the main river is increasing from upstream to downstream area, except for stations 15, 22 and 27 (Appendix 19) in the year 2015. From Appendix 20, higher flows were observed in Jan and Mar 2016 than in Jan 2015 of the stations at the tributaries.

3.3.3 Water Quality Parameters

Results of the water quality study arranged in the direction from upstream area in Jul 2015 to midstream area in Sep 2015 and then downstream area in Jan 2015 of the upper Baram River, Sarawak are as shown in Figures 8 to 37.

3.3.3.1 Temperature

Mean temperature of the stations at the upstream area of the upper Baram River ranged from 24.03 to 26.31 °C is shown in Figure 8. Station 10 at Moh River, a tributary, showed significantly lower mean temperature than the other stations at the upstream area. Meanwhile, station 1 at the main river, nearby the longhouse at Lio Mato, was significantly higher in mean temperature than the other stations at the upstream area. Besides, mean temperature of the

stations at the midstream area of the upper Baram River is in the range of 25.52 to 31.41 °C (Figure 8). The highest mean temperature recorded was at station 16 at Menuang River, a tributary, followed by station 17 (30.34 °C) at Lasa River, a tributary, and they were significantly higher in mean temperature than the other tributaries. Besides, the lowest mean temperature recorded was at station 19 at Keluang River, a tributary, followed by station 14 and 15 (25.77 °C). On the other hand, mean temperature of the stations at the downstream area of the upper Baram River ranged from 23.77 to 27.33 °C (Figure 8). The highest mean temperature recorded was at station 28 at Nakan River, a tributary, and was significantly higher in mean temperature than the other stations at the downstream area. Besides, the lowest mean temperature recorded was at station 22 at the main river, downstream of the estuary of Hit River, and was significantly lower mean temperature than the other stations. In addition, the mean temperature of the stations at the main river of the upper Baram River shows a gradual decreasing trend from upstream to downstream area in the year 2015 (Figure 9).

Direct exposure of the river at the tributaries at stations 16, 17, 18, 20, and 28 to solar radiation resulted in significantly higher mean temperature compared to the stations that were not directly exposed to sunlight. The surroundings of these rivers were less shaded and sampling was in the afternoon. Ngoye & Machiwa (2003) also stated that temperature was lower in forested areas and higher in plain areas where the air temperature was higher. Thus, the mean temperatures of the stations at the upstream area were lower than the stations at the midstream area. Stations 10, 22, 23 and 24 recorded lower mean temperature than the other stations due to the cloudy weather and light rain occurring during the sampling and the continuous rain for one week prior to that sampling. In addition, the slower moving water was observed at the tributaries of the Baram River during sampling and faster moving water was observed at the main river. Higher

mean temperature recorded at stations 16, 17 and 18, was also due to the slower moving water as the mean velocity at the stations only showed 0.11, 0.07 and 0.25 m/s respectively. This is also supported by the negative correlation of the stations of temperature and mean velocity ($r = -0.377$, $P = 0.007$, $n = 50$). Ling *et al.* (2010b) also found that temperature was higher during low flow than high flow at residential areas in Kuching city.

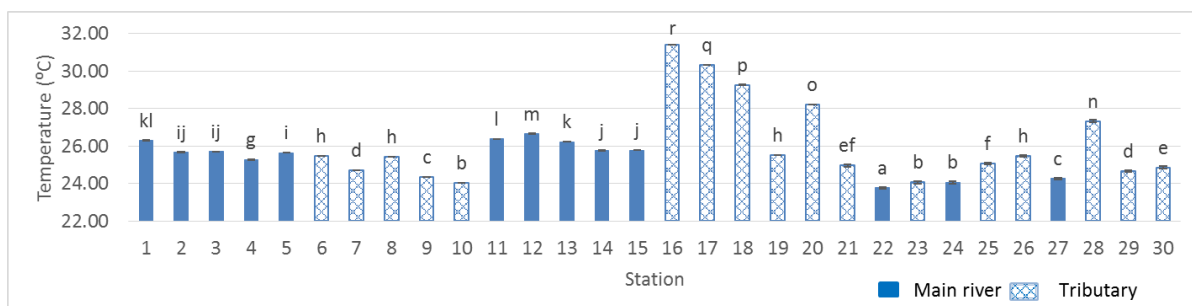


Figure 8: Mean temperature (°C) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

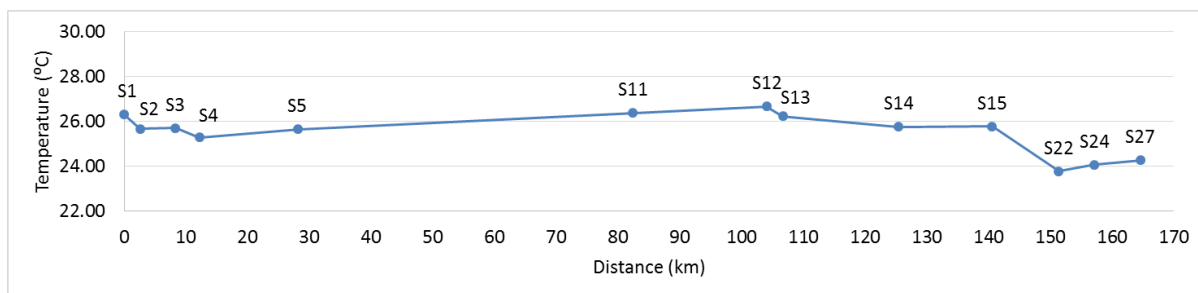


Figure 9: Mean temperature (°C) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.2 Dissolved Oxygen (DO)

Figure 10 shows that the mean DO concentration of the stations at the upstream area of the upper Baram River is in the range of 6.41 to 6.94 mg/L. Station 10 at Moh River, a tributary, recorded the highest mean DO concentration followed by station 7 (6.76 mg/L) at Temedan River, a tributary. The lowest mean DO concentration was at station 6 (6.41 mg/L) at Selungo

River, a tributary. Besides, the mean DO concentration of the stations at the midstream area of the upper Baram River ranged from 6.18 to 6.96 mg/L (Figure 10). Station 19 at Keluang River, a tributary, showed significantly higher mean DO concentration than the other tributaries. Meanwhile, station 16 at Menuang River, a tributary, showed significantly lower mean DO concentration than the other tributaries. The mean DO concentration of the stations at downstream area of the upper Baram River ranged from 5.91 to 7.59 mg/L (Figure 10). The highest and second highest mean DO concentration was located at station 24 (7.59 mg/L) at the main river, downstream of the estuary of Tanan River, and station 27 (7.32 mg/L) at the main river, next to longhouse at Long Kesseh, respectively (Figure 10). Stations 24 and 27 have significantly higher mean DO concentration than the other stations. Besides, station 30 (5.91 mg/L) at Kemenyeh River, a tributary, showed significantly lower mean DO concentration than the other tributaries (Figure 10). The mean DO concentration of the stations at the main river stations of the upper Baram River shows a gradual increasing trend from upstream to downstream area in the year 2015 (Figure 11).

From Appendix 21, it can be seen that DO of all the stations from upstream to downstream area fall in Class II classification of NWQS for Malaysia, except for stations 24 and 27 which fall in Class I classification. The significantly higher mean DO concentration recorded at stations 24 and 27 than other stations are mainly due to the fast flowing river water at stations 24 and 27 which recorded the mean velocity at 0.57 and 0.72 m/s respectively. The high turbulence of the river caused higher exchange rate of oxygen gas from the atmosphere into the river. This is supported by Loucks *et al.* (2005), as the higher the stream velocity, the higher the oxygen concentration in the river. Significantly lower mean DO concentration was observed at stations 6, 16, 25, and 30, were most likely due to oxygen being used up to break down organic matter

from the waste discharged from the nearby logging camp. Amneera *et al.* (2013) and Yisa & Jimoh (2010) also stated that the organic waste that was discharged into the river had decreased the DO concentration. The higher mean temperature at station 16 also caused mean DO concentration to be lower since the solubility of oxygen decreases with an increase in temperature.

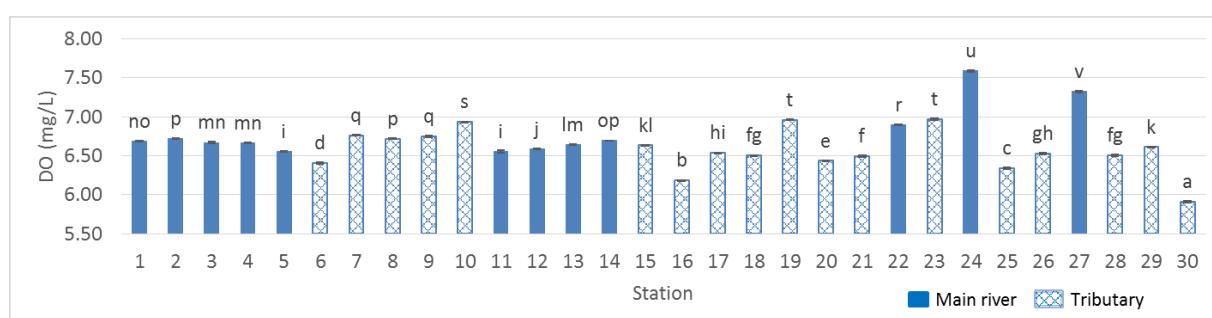


Figure 10: Mean DO (mg/L) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

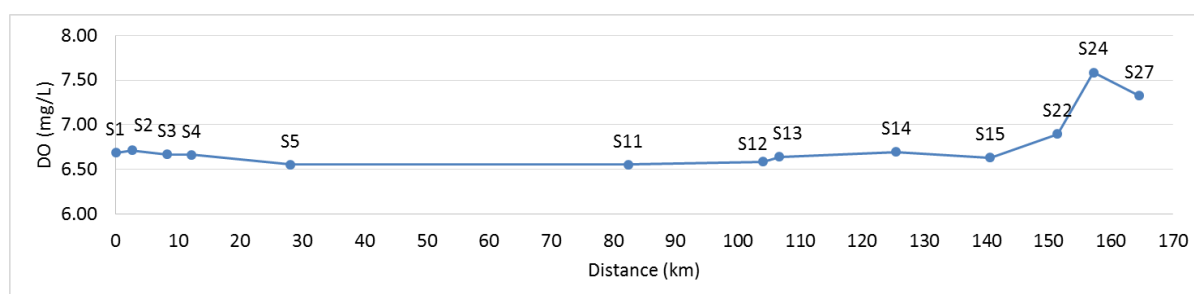


Figure 11: Mean DO (mg/L) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.3 Specific conductance

Figure 12 illustrates that the highest mean specific conductance of the stations at the upstream area of the upper Baram River was at station 1 (49.95 $\mu\text{S}/\text{cm}$) at the main river, downstream of longhouses at Lio Mato, and the second highest mean specific conductance was at station 3

(40.10 $\mu\text{S/cm}$) at the main river, downstream of the estuary of Temendan River, and they were significantly higher in mean specific conductance than the other stations at the upstream area. Besides, station 10 (24.98 $\mu\text{S/cm}$) at Moh River, a tributary, was significantly lower in mean specific conductance than the other stations at the upstream area. Furthermore, the mean specific conductance of the stations at the midstream area of the upper Baram River ranged from 28.10 to 73.90 $\mu\text{S/cm}$ (Figure 12). The highest and the second highest mean specific conductance was at station 16 at Menuang River, a tributary, and station 17 (66.91 $\mu\text{S/cm}$) at Lasa River, a tributary, respectively. Stations 16 and 17 were significantly higher in mean specific conductance than the other tributaries. However, station 14 at the main river, downstream of longhouses at Long Sangah, recorded the lowest mean specific conductance. The lowest and the second lowest mean specific conductance at the downstream area of the upper Baram River was located at station 29 (3.49 $\mu\text{S/cm}$) at Liyans River, a tributary, and station 24 (8.47 $\mu\text{S/cm}$) at the main river, downstream of the estuary of Tanan River, respectively (Figure 12). Stations 24 and 29 were significantly lower in mean specific conductance than the other stations. The highest mean specific conductance recorded was at station 30 (76.33 $\mu\text{S/cm}$) at Kemenyeh River, a tributary, and it was significantly higher in mean specific conductance than the other stations. The mean specific conductance of the stations at the main river of the upper Baram River shows a decreasing trend from upstream to downstream area in the year 2015, except for station 27 (Figure 13).

Specific conductance of all the stations sampled in the year 2015 fall in Class I (Appendix 21). Significantly higher mean specific conductance at stations 16, 17 and 30 than the other tributaries. This is likely because of the intensity of the logging activities which increased in the downstream direction. Higher mean specific conductance of the rivers was likely due to the

runoff of domestic effluents from logging sites and fertilizers from agricultural land containing high inorganic ions (Bahar *et al.*, 2008; Shrestha & Kazama, 2007). Therefore, conductivity was strongly related with agriculture land and residential area. Tong & Chen (2002) also found that conductivity showed the highest at agriculture land followed by residential area.

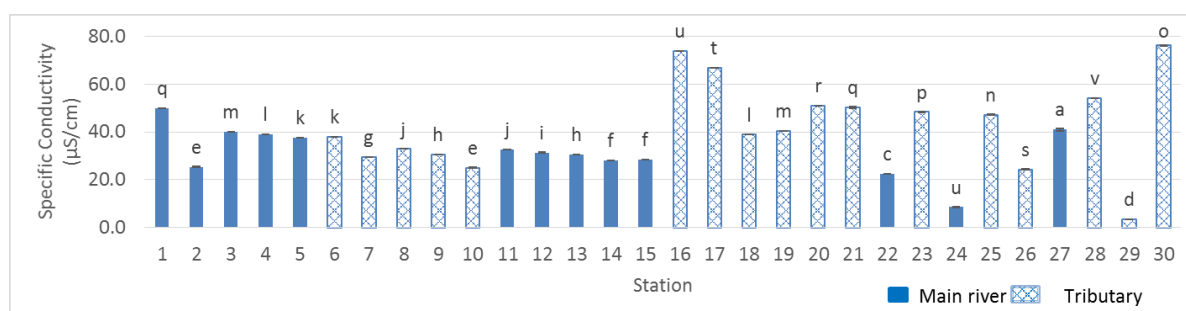


Figure 12: Mean specific conductance ($\mu\text{S}/\text{cm}$) at different stations from upstream (St 1-10) in July, 2015 to midstream (St 11-20) in Sep, 2015, then downstream (St 21-30) in Jan, 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

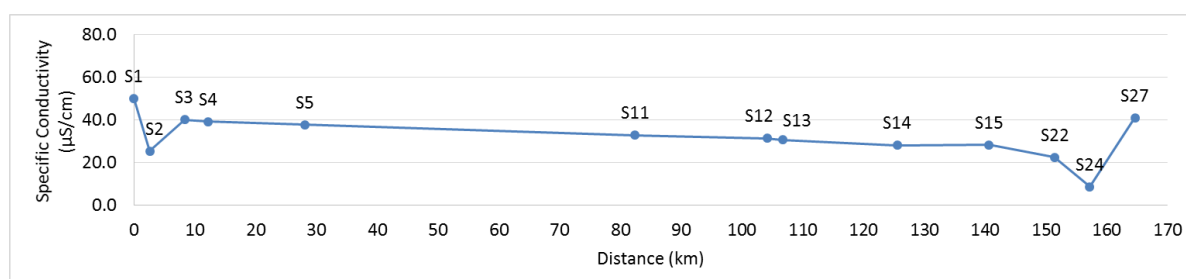


Figure 13: Mean specific conductance ($\mu\text{S}/\text{cm}$) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.4 Water pH

The mean pH value of the stations at the upstream area of the upper Baram River ranged from pH 6.77 to 7.18 (Figure 14). The highest and the second highest mean pH value recorded was at station 1 at the main river, downstream of the longhouses at Lio Mato, and station 4 (pH 7.06) at the main river, downstream of longhouses of Long Semiyang, respectively. On the other hand, the lowest mean pH value was located at station 10 at Moh River, a tributary, followed by

station 9 (pH 6.83) at Sela'an River, a tributary. Stations 9 and 10 were significantly lower in mean pH value than the other tributaries. Besides, the mean pH value of the stations at the midstream area of the upper Baram River is in the range of pH 7.06 to 7.77 as presented in Figure 14. The lowest mean pH value at station 11 at the main river, downstream of longhouses at Long Apu, showed significantly lower value than the other stations. However, the highest and the second highest mean pH value recorded was at station 20 at Patah River, a tributary, and station 17 (pH 7.76) at Lasa River, a tributary, respectively. Stations 17 and 20 have significantly higher mean pH value than the other tributaries but there is no significant difference between stations 17 and 20. Figure 14 shows that the mean pH value of the stations at the downstream area of the upper Baram River ranged from pH 6.79 to 7.50. Station 21 at Kahah River, a tributary, showed significantly higher mean pH value than the other stations at the downstream area. On the other hand, station 22 (pH 6.79) at the main river, downstream of the estuary of Hit River, and station 27 (pH 6.80) at the main river, next to longhouses at Long Kesseh, showed significantly lower mean pH value than the other stations. The mean pH value of the stations at the main river of the upper Baram River shows a decreasing trend from upstream to downstream area in the year 2015, except for station 24 (Figure 15).

Furthermore, pH value of all the stations sampled in the year 2015 fall in Class I (Appendix 21). Significantly lower mean pH was observed at stations 9, 10, 22 and 27 in the year 2015 were likely due to the discharge of domestic effluents from residential areas and logging sites into the rivers. Higher input of nutrients from the untreated effluents resulted in slightly alkaline of the river. Salih *et al.* (2013) also found that lower pH value was mainly due to the untreated effluents such as domestic sewage that was discharged into the river. Significantly higher mean pH value observed at stations 16, 17, 20, and 21 were due to the anthropogenic inputs of

nutrients that enhanced the growth of algae photosynthesis and the release of carbon dioxide thus increasing the mean pH value. Ling *et al.* (2010c) also supported that high pH value could due to the anthropogenic inputs of nutrients that resulted in more photosynthesis.

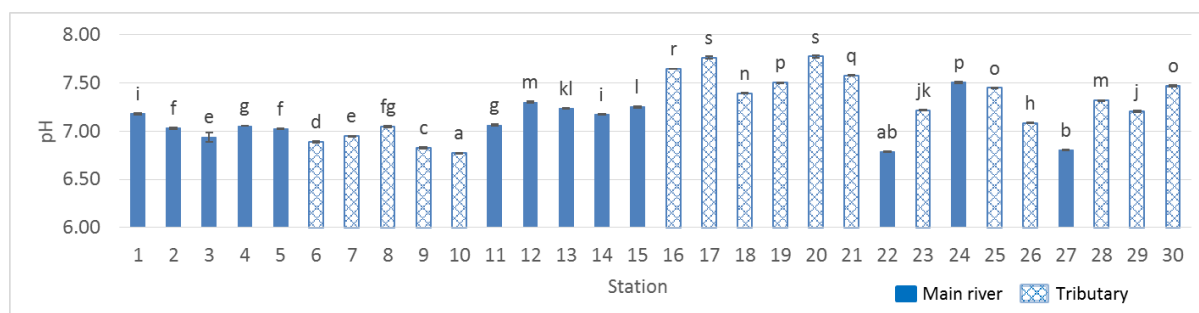


Figure 14: Mean pH value at different stations from upstream (St 1-10) in July, 2015 to midstream (St 11-20) in Sep, 2015, then downstream (St 21-30) in Jan, 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

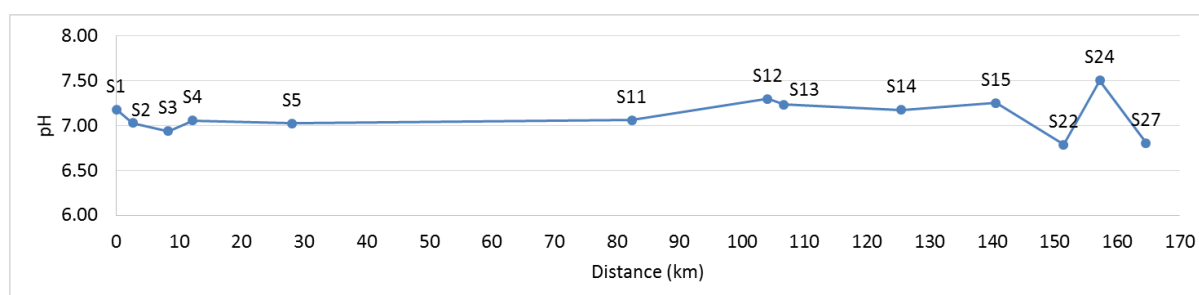


Figure 15: Mean pH value at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.5 Transparency

The mean transparency of the stations at the upstream area of the upper Baram River is in the range of 0.05 to 0.53 m (Figure 16). The highest mean transparency recorded was at station 9 at Sela'an River, a tributary, followed by station 6 (0.50 m) at Selungo River. Stations 6 and 9 were significantly higher in transparency than the other stations at the upstream area. Besides, significantly higher mean transparency was also observed at the tributaries, Sebatu River and Moh River, which were located at station 8 and 10, respectively. On the other hand,

significantly lower mean transparency were recorded at stations 1, 2, 3, 4, and 5, which are located at the main river, and station 7, which is located at a tributary than the other stations. The highest mean transparency of the stations at the midstream area of the upper Baram River was at station 19 (0.36 m) at Keluang River, a tributary, and the second highest mean transparency at station 18 (0.24 m) at Akah River, a tributary, followed by station 16 (0.19 m) at Menuang River, a tributary and they have significantly higher values than the other stations at the midstream area (Figure 16). The other stations at midstream area of the upper Baram River showed the mean transparency of less than 0.5 m and they are not significantly different. Station 21 (1.05 m) at Kahah River, a tributary, and station 23 (1.05 m) at Piping River, a tributary, followed by station 28 (1.03 m) at Nakan River, a tributary, at the downstream area of the upper Baram River recorded the highest and the second highest mean transparency. Stations 21, 23 and 28 have significantly higher mean transparency than the other tributaries. Moreover, stations 22, 24 and 27 at the main river, followed by station 29 at tributaries showed significantly lower mean transparency than the other stations. The mean transparency of the stations at the main river of the upper Baram River shows a similar trend from upstream to downstream area in the year 2015 (Figure 17). Significantly lower transparency of the stations were observed at the main river. This could be due to the soil erosion that resulted from logging activities. Salih *et al.* (2013) also reported that low transparency was due to the soil erosion within the Sungai Pinang River basin in the state of Penang.

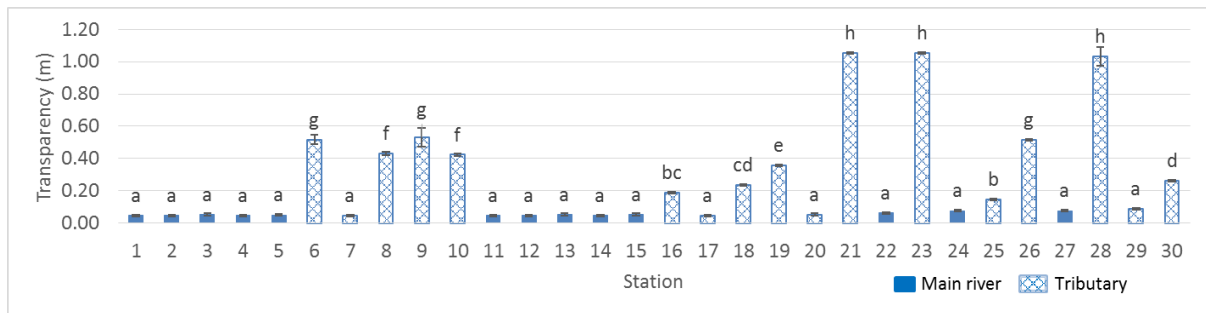


Figure 16: Mean transparency (m) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

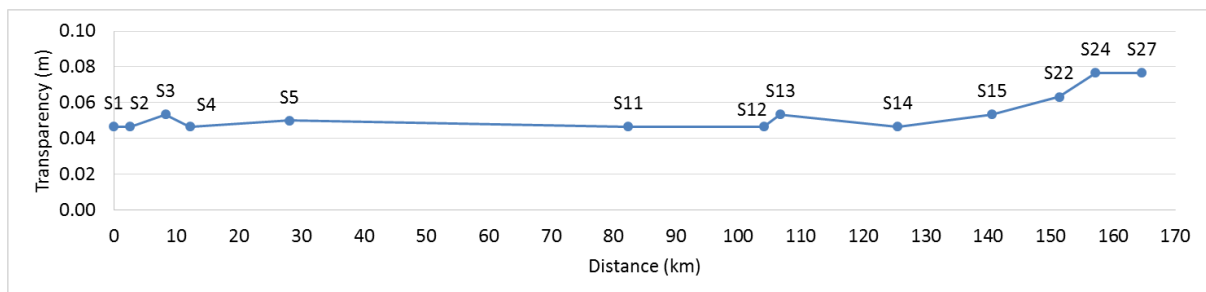


Figure 17: Mean transparency (m) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.6 Turbidity

Figure 18 illustrates that station 7 (205.9 NTU) at Temedan River, a tributary, at the upstream area of the upper Baram River has significantly higher mean turbidity than the other stations followed by station 4 (199.0 NTU) at the main river at Long Semiyang, and station 5 (198.9 NTU) at Long Moh. Stations 4, 5 and 7 have significantly higher turbidity than the other stations at the upstream area. Station 9 (66.7 NTU) at Sela'an River, a tributary, followed by station 6 (74.8 NTU) at the Selungo River, a tributary, showed significantly lower mean turbidity than the other tributaries at the upstream area. The mean turbidity of the stations at the midstream area of the upper Baram River ranged from 7.4 to 468.8 NTU is illustrated in Figure 18. Station 20 (468.8 NTU) at Patah River, a tributary, has significantly higher mean turbidity than the

other tributaries. Meanwhile, the second highest was at station 12 (326.7 NTU) at the main river, upstream of Long San's bridge. On the contrary, station 11 at the main river, downstream of longhouses at Long Apu has significantly lower mean turbidity than the other stations. Figure 18 shows that station 22 (454.7 NTU) at the main river, downstream of the estuary of Hit River at the upstream area of the Baram River was significantly higher in mean turbidity than the other stations followed by stations 24 (288.3 NTU), 27 (290.7 NTU) and 29 (281.3 NTU). Stations 22, 24, 27, and 29 have significantly higher mean turbidity than the other stations. Station 28 (9.5 NTU) at Nakan River, a tributary, has significantly lower mean turbidity than the other stations, followed by stations 21 (9.81 NTU), 23 (42.5 NTU), 26 (18.6 NTU), and 30 (35.7 NTU). Stations 21, 23, 26, 28, and 30 have significantly lower turbidity than the other stations but there is no significant difference between stations 21, 23, 26, 28, and 30. Figure 19 shows the trend of the mean turbidity of the stations at the main river of the upper Baram River. The mean turbidity of the stations at the main river gradually increased from upstream to downstream area, except for station 11 in the year 2015.

For turbidity classification, stations 11, 16, 18, 19, 21, 23, 26, 28, and 30 fall in Class II of NWQS for Malaysia, whereas, all the other stations exceeded Class II (Appendix 21). In addition, significantly higher mean turbidity at stations 20 and 22 were caused by the increase of suspended particles in the rivers from the surface runoff due to heavy precipitation at the nearby logging sites. Ling *et al.* (2016) also stated that the presence of logging activities caused the higher turbidity and TSS concentration in the river. Besides, transparency are negatively correlated with turbidity. The high turbidity at the stations 12, 14, 15, 24 and 27 in the year 2015 also caused the mean transparency to be lower since the murkier the river water the lower the transparency. The presence of suspended particles had decreased the clarity of the water,

therefore, the murkier the river, the higher the turbidity of the river. Fawaz *et al.* (2013) also stated that high turbidity was attributed to the effluents from livestock farms, and heavy precipitation.

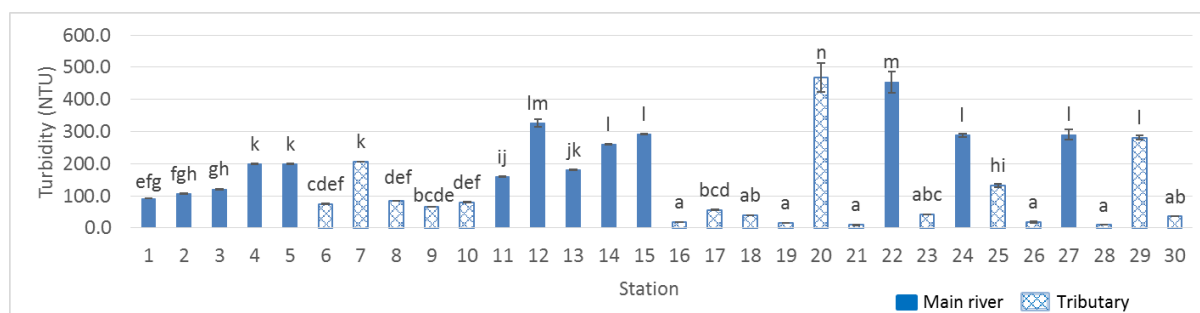


Figure 18: Mean turbidity (NTU) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

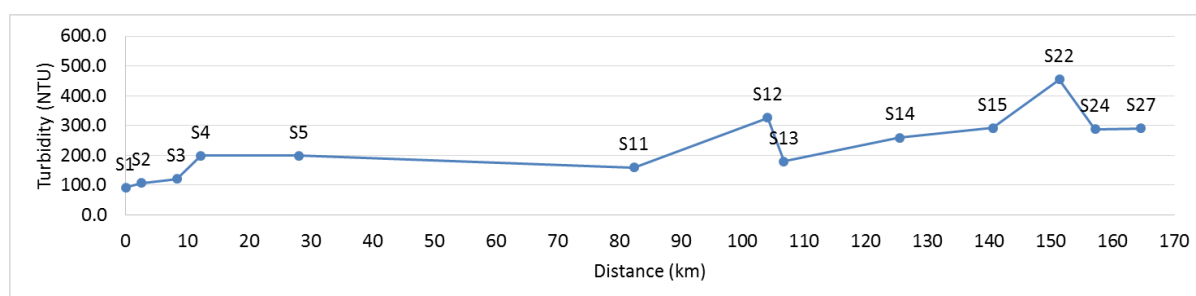


Figure 19: Mean turbidity (NTU) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.7 Total Suspended Solids (TSS)

The mean TSS concentration of the stations at the upstream of the upper Baram River ranged from 33 to 160 mg/L is shown in Figure 20. The lowest concentration was at station 6 at Selungo River, a tributary. The highest mean TSS concentration was at station 4 at the main river, downstream of longhouses at Long Semiyang, followed by station 7 (153 mg/L) at Temendan River, a tributary and they have significantly higher mean TSS concentration than the other stations at the upstream area. The mean TSS concentration of the stations at the midstream of

the upper Baram River was in the range of 13 to 320 mg/L (Figure 20). The highest mean TSS concentration was at station 20 at Patah River, a tributary, followed by station 15 (318 mg/L) at the main river, downstream of longhouses at Long Na'ah and they have significantly higher mean TSS concentration than the other stations. The lowest mean TSS concentration was at station 16 at Akah River, a tributary, followed by stations 17, 18 and 19. Stations 16, 17, 18, and 19 have significantly lower mean TSS concentration than the other stations. The mean TSS concentration of the stations at the downstream of the upper Baram River ranged from 6 to 267 mg/L is shown in Figure 20. The highest and the second highest mean TSS concentration was at station 24 at the main river, downstream of the estuary of Tanan River and station 22 (246 mg/L) at the main river, downstream of longhouses at Long Na'ah, respectively. The lowest mean TSS concentration was at station 21 at Kahah River, a tributary, followed by stations 23 (40 mg/L), 26 (7 mg/L), 28 (6 mg/L), and 30 (21.33 mg/L). Stations 21, 23, 26, 28, and 30 have significantly lower mean TSS concentration than the other stations. The mean TSS concentration of the stations at the main river of the upper Baram River shows a gradual increasing trend from upstream to midstream area and a gradual decreasing trend from midstream to downstream area (Figure 21).

Additionally, TSS classification according to NWQS for Malaysia of the stations 16, 17, 21, 26, 28, and 30 shows Class I, whereas, stations 6, 9, 18, 19, and 23 fall in Class II (Appendix 21). Besides, the other stations fall in Class III, IV or V of NWQS for Malaysia (Appendix 21). High mean TSS concentration observed at stations 14, 15, 20, 22, 24 and 27 in the year 2015 were due to the area source such as runoff from logging sites at the upstream area of upper Baram River with high suspended matter content, which coincided with continuous rain for one

week prior the sampling. In addition, Ling *et al.* (2016) also stated that the presence of logging activities at the upper reaches of the Baleh River, causes the higher turbidity and TSS.

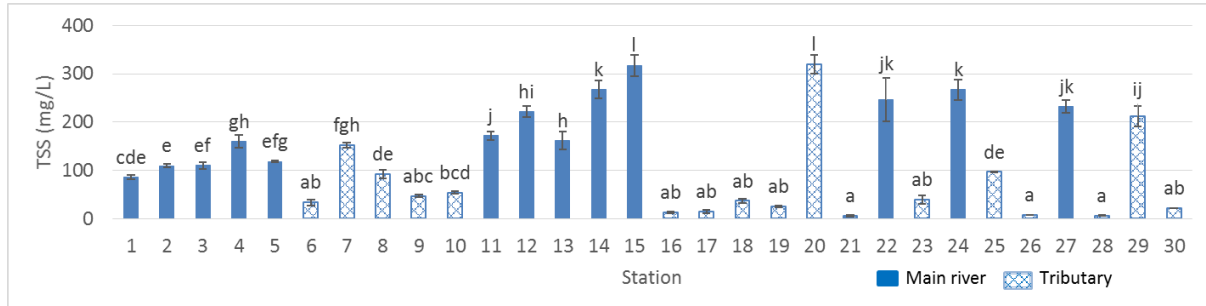


Figure 20: Mean TSS (mg/L) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

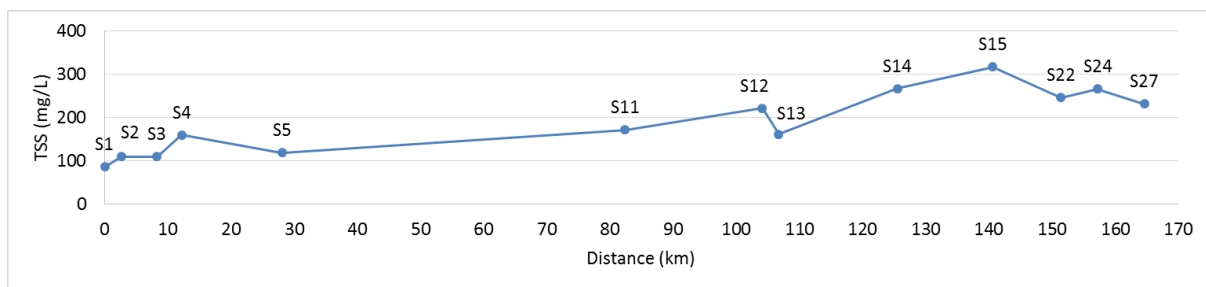


Figure 21: Mean TSS (mg/L) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.8 Chlorophyll-*a* (Chl-*a*)

From Figure 22, it can be seen that both stations 9 (24.6 mg/m³) at Sela'an River, and station 10 (17.9 mg/m³) at Moh River, a tributary at upstream area of the upper Baram River were observed to have significantly higher mean Chl-*a* concentration than the other tributaries. Station 4 (0.9 mg/m³) at the main river, downstream of longhouses at Long Semiyang, was significantly lower in mean Chl-*a* concentration followed by stations 1 (1.6 mg/m³), 2 (1.9 mg/m³), 3 (1.9 mg/m³), and 6 (1.0 mg/m³). The highest mean Chl-*a* concentration of the stations at the midstream area of the upper Baram River was at station 18 (11.1 mg/m³) at Akah River,

a tributary, and the second highest mean Chl-*a* concentration was at station 20 (8.3 mg/m³) at Patah River, a tributary (Figure 22). Stations 18 and 20 have significantly higher mean Chl-*a* concentration than the other tributaries at the midstream area. Station 19 at Keluang River, a tributary, recorded the lowest mean Chl-*a* concentration (0.36 mg/m³) followed by station 17 (1.2 mg/m³) at Lasa River, a tributary. Stations 17 and 19 were significantly lower in mean Chl-*a* concentration than the other stations at the midstream area. Based on Figure 22, the lowest mean Chl-*a* concentration of the stations at the downstream of the upper Baram River was at station 25 (0.16 mg/m³) at Jertang River, a tributary, followed by stations 21 (0.9 mg/m³), 22 (1.3 mg/m³), 23 (0.3 mg/m³), 24 (1.1 mg/m³), 26 (1.8 mg/m³), and 30 (0.31 mg/m³). Stations 21, 22, 23, 24, 25, 26, and 30 have significantly lower mean Chl-*a* concentration than the other stations at the downstream area. Station 29 (23.3 mg/m³) at Liyans River, a tributary, was significantly higher in mean Chl-*a* concentration than the other tributaries, followed by station 27 (13.1 mg/m³) at the main river, next to longhouses at Long Kesseh and station 28 (11.9 mg/m³) at Nakan River, a tributary. However, stations 27 and 28 are not significantly different in mean Chl-*a* concentration. The trend of the Chl-*a* concentration of the stations at the main river of the upper Baram River shows a gradual increasing trend from upstream to midstream area followed by a decreasing trend from midstream to downstream area, except for station 27 (Figure 23).

Significantly higher mean Chl-*a* concentration was observed at the stations 9, 10 and 29 than the other stations. This is mainly due to the discharge of domestic waste and animal manure from the upstream longhouses into the river. Neal *et al.* (2006) stated that high turbidity affecting the amount of light that reaches into the water. Stations 9 and 10 were observed to have low turbidity and TSS which enhance photosynthetic production, thus high chlorophyll-*a*

was observed. In the study conducted by Ling *et al.* (2011) on the impacts of aquaculture and domestic wastewater on the water quality of Santubong River, Malaysia, the mean Chl-*a* concentration was due to the discharge of nutrients from residential areas into the river.

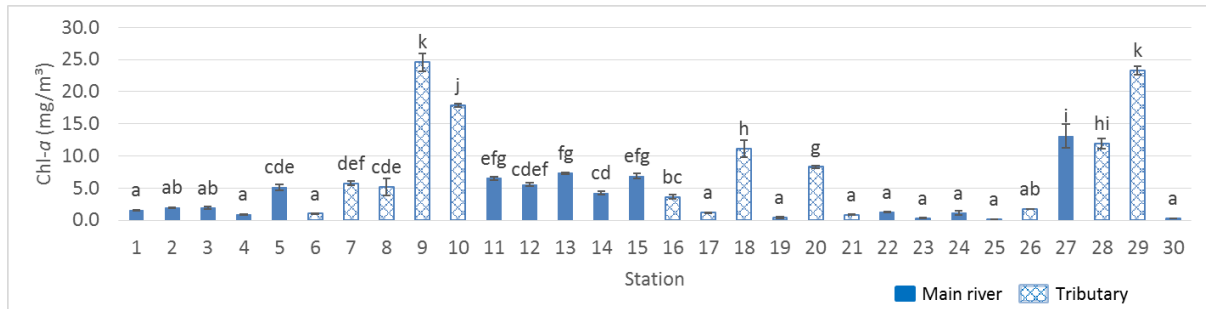


Figure 22: Mean Chl-*a* (mg/m³) concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

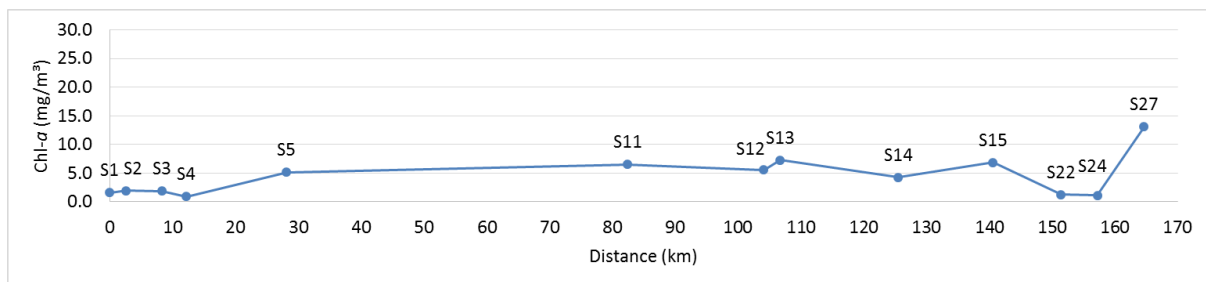


Figure 23: Mean Chl-*a* (mg/m³) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.9 Five-days Biochemical Oxygen Demand (BOD₅)

Station 1 (5.70 mg/L) at the main river, downstream of longhouses at Lio Mato, was significantly higher in mean BOD₅ concentration at the upstream area of the upper Baram River than the other stations (Figure 24). The second highest mean BOD₅ concentration was at station 10 (4.63 mg/L) at Moh River, a tributary. The lowest mean BOD₅ concentration was at station 4 (2.79 mg/L) at the main river, downstream of longhouses at Long Semiyang. The mean BOD₅ concentration of the stations at the midstream area of the upper Baram River ranged from 1.72

to 3.98 mg/L is shown in Figure 24. Station 12 at the main river, downstream of Long San's bridge showed the highest mean BOD₅ concentration, and has significantly higher mean BOD₅ concentration than the other stations at the midstream area. The second highest mean BOD₅ concentration was at station 14 (3.54 mg/L) at the main river, downstream of longhouses at Long Sangah, followed by station 13 (3.47 mg/L) at the main river, downstream of longhouses at Long San. Station 18 at Akah River, a tributary, has significantly lower in mean BOD₅ concentration than the other stations, followed by stations 17, 19 and 20. Figure 24 shows that the mean BOD₅ concentration of the stations at the downstream area of the upper Baram River is in the range from 1.25 to 2.86 mg/L. Significantly higher in mean BOD₅ concentration than the other stations at the downstream area was observed at station 30 at Kemenyeh River, a tributary, followed by station 25 (2.60 mg/L) at Jertang River, a tributary. Significantly lower in mean BOD₅ concentration than the other tributaries was observed at station 26 at Kesseh River, a tributary. The trend of the BOD₅ concentration of the stations at the main river of the upper Baram River shows a general decreasing trend from upstream to downstream area in the year 2015 (Figure 25).

The mean BOD₅ concentration of the upstream and midstream areas at the upper Baram River mostly exceeded Class II (Appendix 21) due to the runoff from the logging site upstream of the river especially organic pollutants and the logging camp sewage. Organic materials discharged into the river can lead to oxygen depletion as decomposition process by microorganism consumes oxygen. This is supported by Gandaseca *et al.*, (2011) by saying that high BOD concentration in the river was likely because of more organic matter such as debris that enter the river through wastewater and storm runoff. Hossain *et al.* (2013) also stated that high BOD indicated the presence of organic pollutants from effluents. Station 1 at the main river,

downstream of longhouses at Lio Mato, has significantly higher mean BOD concentration than the other stations was due to the discharge of untreated wastewater from residential area and logging sites upstream. Ling *et al.* (2010b) reported that untreated and partially treated household waste flushed into the river water led to higher BOD concentration.

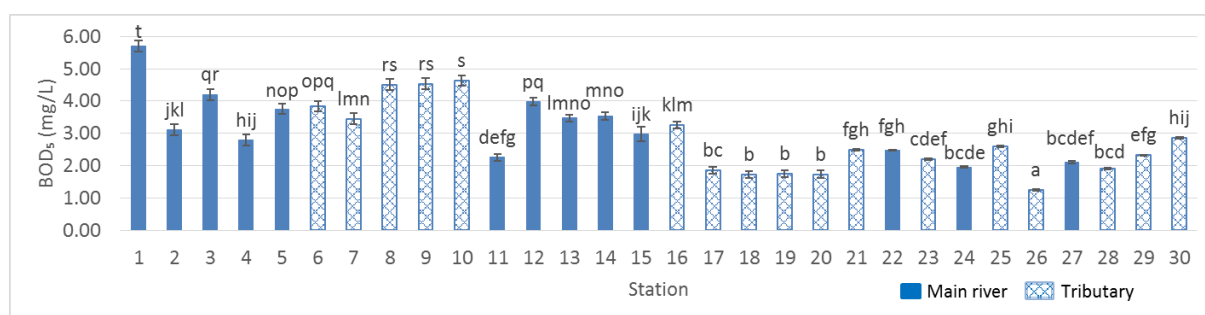


Figure 24: Mean BOD₅ (mg/L) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

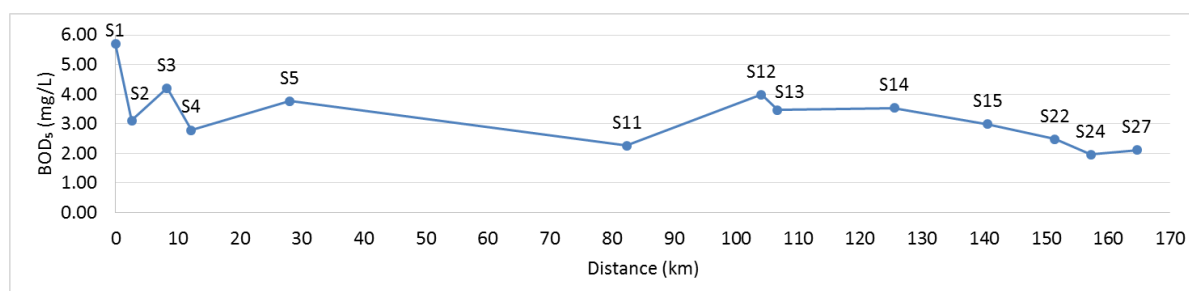


Figure 25: Mean BOD₅ (mg/L) concentration at different stations at the main river stations showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.10 Chemical Oxygen Demand (COD)

The range of the mean COD concentration of the stations at the upstream area of the upper Baram River was from 25.5 to 94.4 mg/L (Figure 26). Station 8 at Sebatu River, a tributary, and 1 (79.1 mg/L) at the main river, downstream of longhouses at Lio Mato, was recorded as the highest and second highest mean COD concentration respectively. Station 8 showed

significantly higher COD concentration than the other stations at the upstream area. Station 4 at the main river, downstream of longhouses at Long Semiyang, recorded the lowest mean COD concentration and it has significantly lower mean COD concentration than the other stations. Station 19 (84.5 mg/L) at Keluang River, a tributary, recorded the lowest mean COD concentration at the midstream area of the upper Baram River (Figure 26). Significantly higher in mean COD concentration was observed at station 12 (181.8 mg/L), followed by station 13 (143.4 mg/L) at the main river, downstream of longhouse at Long San, and station 14 (138.3 mg/L) at the main river, downstream of longhouses at Long Sangah. The mean COD concentration of the stations at the downstream area of the upper Baram River ranged from 21.3 to 256.0 mg/L is shown in Figure 26. Station 25 at Jertang River, a tributary, was significantly higher in mean COD concentration than the other tributaries. Significantly higher in mean COD concentration was also observed at station 30 (165 mg/L) at Kemenyeh River, a tributary, than the other stations. Meanwhile, station 27 at the main river, next to Long Kesseh, showed significantly lower mean COD concentration than the other stations, followed by stations 24 (32.0 mg/L), 26 (21.3 mg/L) and 27 (21.3 mg/L). The mean COD concentration of the stations at the main river of the upper Baram River shows an increasing trend from the upstream to the midstream area and decreasing trend from midstream to the downstream area (Figure 27).

For COD classification, only stations 26 and 27 in the year 2015 fall in Class II of NWQS for Malaysia (Appendix 21). The COD class of the other stations in the year 2015 is Class III (9 stations), IV (9 stations) and V (10 stations) of NWQS for Malaysia (Appendix 21). Station 25 at Jertang River, a tributary was significantly higher mean COD and lower DO concentrations than the other tributaries. This is because the discharge of untreated effluent and human waste from the logging sites caused the high mean COD and low mean DO concentration. It is likely

due to the oxygen concentration consumed by the microorganism to undergo decomposition of organic matter. This is supported by Nor Zaiha *et al.* (2015) who reported high COD concentration in the river due to the runoff from logging sites during heavy precipitation. Furthermore, in the study on water quality of river, lake and drinking water supply in Penang state, it was shown that COD concentration at Sungai Pinang River was very high in concentration which reached to 1100.0 mg/L due to the discharge of the untreated effluent such as sewage and agricultural waste into the river (Salih *et al.*, 2013).

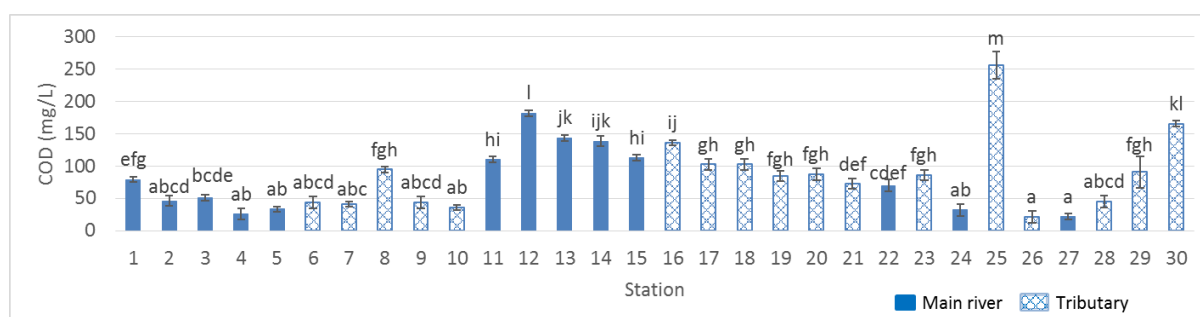


Figure 26: Mean COD (mg/L) concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

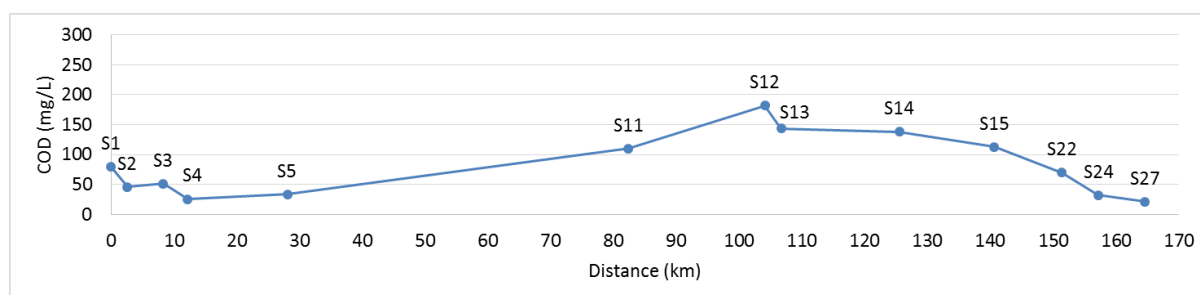


Figure 27: Mean COD (mg/L) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.11 Total Phosphorus (TP)

The mean TP concentration of the stations at the upstream area of the upper Baram River ranged from 161.2 to 2016.7 $\mu\text{g/L}$ is presented in Figure 28. The highest mean TP concentration was observed at station 4 at the main river, downstream of the longhouses at Long Semiyang and the second highest mean TP concentration was at station 1 (1468.5 $\mu\text{g/L}$) at the main river, downstream of longhouses at Lio Mato. Stations 1 and 4 have significantly higher mean TP concentration than the other stations. Station 8 at Sebatu River, a tributary, was significantly lower in mean TP concentration than the other stations, followed by station 10 at Moh River, a tributary (Figure 28). The highest mean TP concentration at the midstream area of the Baram River was at station 12 (689.5 $\mu\text{g/L}$) at the main river, upstream of Long San's bridge and the second highest was at station 11 (669.0 $\mu\text{g/L}$) at the main river, downstream of longhouses at Long Apu (Figure 28). Significantly lower mean TP concentration was observed at station 19 (45.1 $\mu\text{g/L}$) at Keluang River, a tributary, followed by station 20 (56.5 $\mu\text{g/L}$) at Patah River, a tributary. The mean TP concentration of the stations at the downstream of the Baram River ranged from 10.7 to 486.0 $\mu\text{g/L}$ are as shown in Figure 28. The highest mean TP concentration was at station 22 at the main river, downstream of the estuary of Hit River and it has significantly higher mean TP concentration than the other stations at the downstream area. The lowest mean TP concentration was at station 25, Jertang River, a tributary, followed by station 24 (19.6 $\mu\text{g/L}$) at the main river, downstream of longhouses at Long Sangah. Stations 24 and 25 were significantly lower in mean TP concentration than the other stations, followed by stations 20, 26, 29 and 30 (Figure 28). The mean TP concentration of the stations at the main river of the upper Baram River shows a decreasing trend from upstream to downstream area (Figure 29).

Stations 1, 4, 6, 7, and 9 in the year 2015 were observed to have significantly higher mean TP concentration than the other stations. The high level of total phosphorus in the river originated from municipal wastewater discharges from nearby longhouses and logging camp. The disposal of human, animal and household wastes from nearby longhouses that contained high levels of organic phosphorus can cause high mean TP concentration in the river. From Figure 28, a sudden increase of TP concentration from station 3 to 4 may due to the highly TP input from station 7. Besides, a sudden decrease of TP concentration from station 4 to 5 may due to the dilution input from stations 8, 9 and 10 at the tributaries (Figure 28).

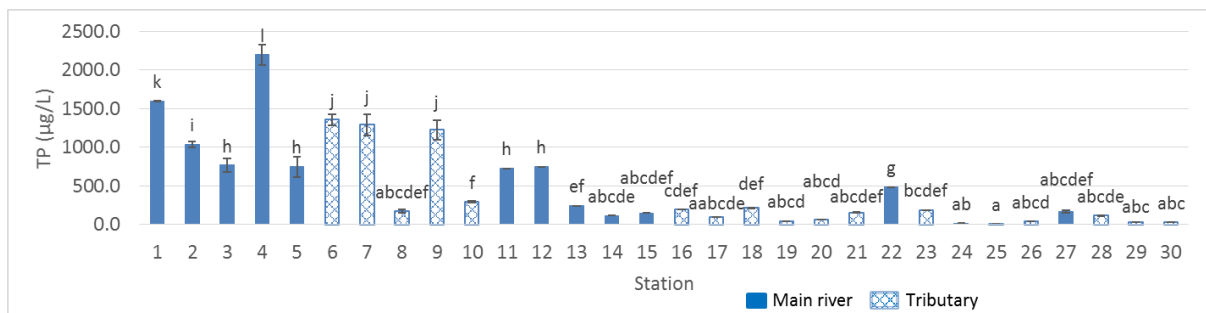


Figure 28: Mean TP (µg/L) concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

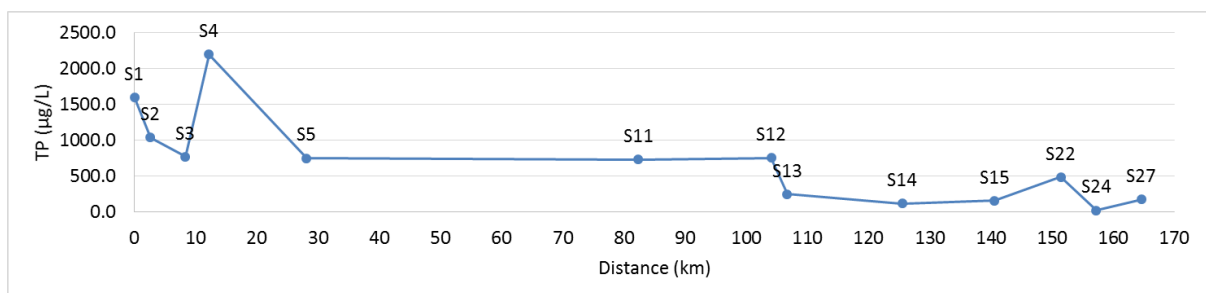


Figure 29: Mean TP (µg/L) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.12 Nitrite-Nitrogen (NO₂-N)

The mean NO₂-N concentration of the stations at the upstream area of the upper Baram River was in the range of 0.007 to 0.038 mg/L (Figure 30). Significantly higher mean NO₂-N concentration than the other tributaries was observed at station 7 at Temedan River, a tributary, followed by station 6 (0.025 mg/L) at Selungo River, a tributary. Besides, the lowest mean NO₂-N concentration was at station 1 at the main river, downstream of longhouses at Lio Mato, and station 9 at Sela'an River, a tributary. The mean NO₂-N concentration of the stations at the midstream area of the upper Baram River ranged from 0.000 to 0.055 mg/L as illustrates in Figure 30. Station 12 at the main river, upstream of the Long San's bridge recorded the lowest mean NO₂-N concentration followed by station 11 (0.001 mg/L) at the main river, downstream of longhouses at Long Apu and station 14 (0.001 mg/L) at the main river, downstream of longhouses at Long Sangah. Stations 11, 12 and 14 were significantly lower in mean NO₂-N concentration than the other stations. On the other hand, significantly higher in mean NO₂-N concentration than the other tributaries was observed at station 20 at Patah River, a tributary. Figure 30 shows that the mean NO₂-N concentration of the stations at the midstream area of the upper Baram River was in the range from 0.002 to 0.009 mg/L. Station 30 at Kemenyeh River, a tributary, was significantly lower in mean NO₂-N concentration than the other stations at the downstream area. Meanwhile, the highest and the second highest mean NO₂-N concentration were at station 25 at Jertang River, a tributary, and station 24 at the main river, downstream of the estuary of Tanan River and station 29 at Liyans River, a tributary (0.008 mg/L). The mean NO₂-N concentration of the stations at the main river of the upper Baram River shows decreasing trend from upstream to the downstream area (Figure 31).

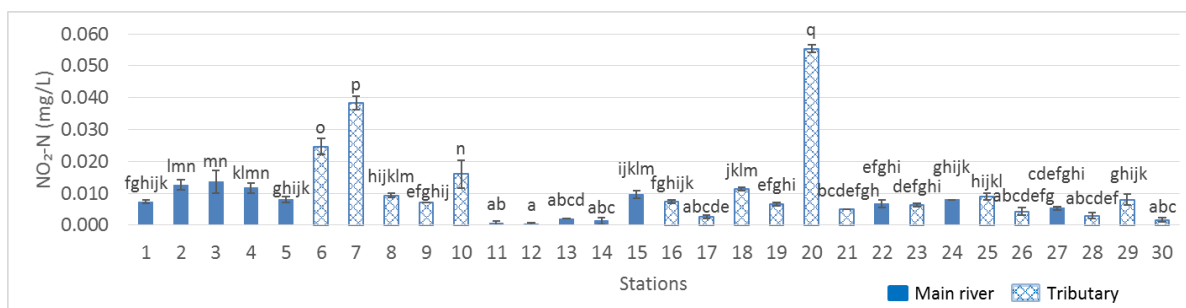


Figure 30: Mean NO₂-N concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

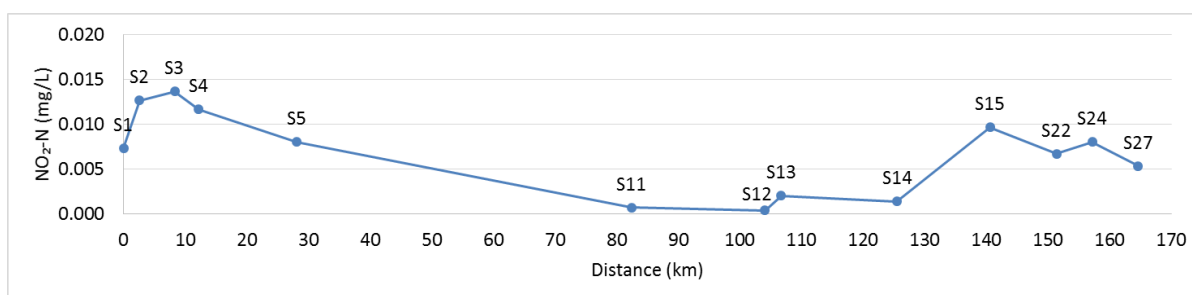


Figure 31: Mean NO₂-N concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.13 Nitrate-Nitrogen (NO₃-N)

Figure 32 shows that the mean NO₃-N concentration of the stations at the upstream area of the upper Baram River is in the range from 0.02 to 0.09 mg/L. The lowest mean NO₃-N concentration was located at station 1 at the main river, downstream of longhouse at Lio Mato, and station 6 at Selungo River, a tributary. The highest and the second highest mean NO₃-N concentration was at station 10 at Moh River, a tributary, and station 7 (0.08 mg/L) at Temedan River, a tributary, respectively. Stations 7 and 10 were significantly higher in mean NO₃-N concentration than the other tributaries. Station 4 (0.07 mg/L) at the main river, downstream of longhouse at Long Semiyang, and station 5 (0.07 mg/L) at the main river, downstream of longhouses at Long Moh, also showed significantly higher mean NO₃-N concentration than the

other stations. In addition, the mean $\text{NO}_3\text{-N}$ concentration of the stations at the midstream area of the upper Baram River ranged from 0.01 to 0.03 mg/L is presented in Figure 32. Station 11 at the main river, downstream of longhouses at Long Apu, recorded the lowest mean $\text{NO}_3\text{-N}$ concentration and it was significantly lower in mean $\text{NO}_3\text{-N}$ concentration than the other stations at the midstream area. The highest mean $\text{NO}_3\text{-N}$ concentration was located at stations 14 and 15 at the main river, and stations 19 and 20 at the tributaries. Figure 32 shows that the mean $\text{NO}_3\text{-N}$ concentration at the downstream area of the Baram River is in the range from 0.01 to 0.03 mg/L. The lowest mean $\text{NO}_3\text{-N}$ concentration was located at station 28 at Nakan River, a tributary, and station 30 at Kemenyeh River, a tributary. Stations 28 and 30 were significantly lower in mean $\text{NO}_3\text{-N}$ concentration than the other tributaries. In addition, the highest mean $\text{NO}_3\text{-N}$ concentration was at station 23 at Piping River, a tributary (Figure 32). The mean $\text{NO}_3\text{-N}$ concentration of the stations at the main river stations of the upper Baram River shows a decreasing trend from upstream to downstream area (Figure 33).

Significantly higher mean $\text{NO}_2\text{-N}$ concentration was observed at stations 6, 7, 10, and 20 and relatively lower mean was observed at stations 4 and 5. In addition, significantly higher mean $\text{NO}_3\text{-N}$ concentration was observed at stations 4, 5, 7, and 10 and relatively lower mean was observed at station 20. These indicate that most of the $\text{NO}_2\text{-N}$ at stations 4 and 5 were converted into $\text{NO}_3\text{-N}$. Besides, $\text{NO}_2\text{-N}$ at station 20 not fully converted to $\text{NO}_3\text{-N}$. The high $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ concentrations observed were due to runoff of partially or untreated waste from the nearby longhouses and logging camp during heavy precipitation. This is supported by Ismail & Ibrahim (2015) by stated that the land use activities contributed high $\text{NO}_3\text{-N}$ concentration in the river and increase the pollution burden on the river. Decay organic matter and excretion that undergoes decomposition and nitrification which converted to ammonia and ammonia oxidized

to nitrite and nitrite further oxidized to nitrate. Furthermore, Cruz *et al.* (2010) also reported that the main drivers of the nutrient enrichment in rivers was mainly diffuse pollution sources associated with wastewater discharges to the river. According to the study of the organic matter, nutrients and trace metals of Serin River, Malaysia, it was reported that NO₃-N concentration ranged from 0.01 to 0.09 mg/L due to the discharge of untreated wastewater into the river (Ling *et al.*, 2010c). Besides, station 6 also has relatively lower mean NO₃-N concentration and significantly lower mean DO concentration than the other stations. This indicates that station 6 has insufficient oxygen concentration to oxidize nitrite to nitrate.

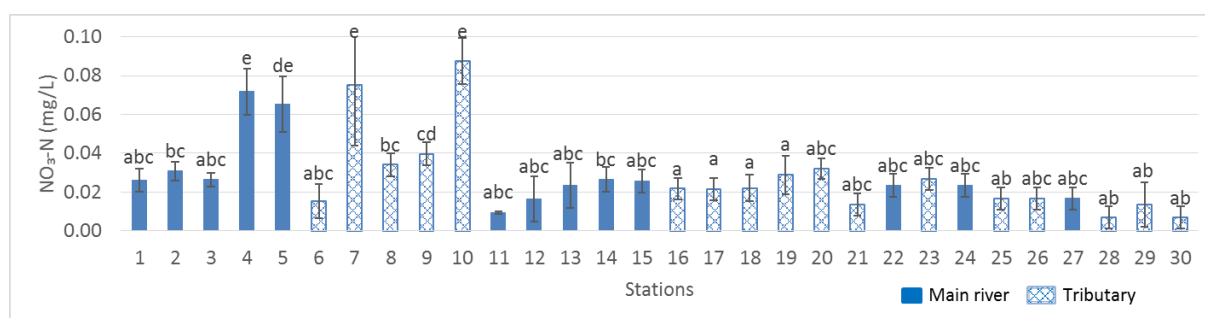


Figure 32: Mean NO₃-N concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

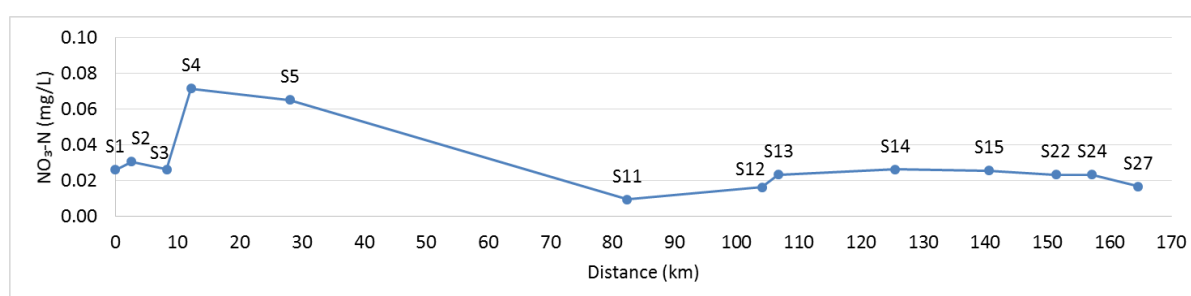


Figure 33: Mean NO₃-N concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.14 Ammonia-Nitrogen (NH₃-N)

Figure 34 presents that the mean NH₃-N concentration of the stations at the upstream area of the upper Baram River was in the range from 0.60 to 0.86 mg/L. The highest mean NH₃-N concentration was observed at station 5 at the main river, downstream of longhouse at Long Moh. The second highest was at station 6 (0.97 mg/L) at Selungo River, a tributary. The lowest mean NH₃-N concentration was observed at station 3 at the main river, downstream of the estuary of Temedan River. The mean NH₃-N concentration of the stations at the midstream area of the upper Baram River ranged 0.01 to 0.31 mg/L (Figure 34). The highest mean NH₃-N concentration was observed at station 13 at the main river, downstream of longhouses at Long San, followed by station 14 (0.19 mg/L) at the main river, downstream of longhouses at Long Sangah. Significantly lower in mean NH₃-N concentration was observed at station 12 at the main river, upstream of Long San's bridge, followed by station 15 at the main river, downstream of longhouses at Long Na'ah, and station 17 at Lasa River, a tributary. In addition, stations 11, 19 and 20 also showed significantly lower mean NH₃-N concentration than the other stations. Based on Figure 34, the mean NH₃-N concentration of the stations at the downstream area of the upper Baram River ranged from 0.23 to 1.57 mg/L. The highest mean NH₃-N concentration was at station 21 at Kahah River, a tributary and the second highest was at station 22 (1.49 mg/L) at the main river, downstream of the estuary of Hit River, and they were significantly higher in mean NH₃-N concentration than the other stations. The lowest mean NH₃-N concentration was at station 29 at Liyans River, a tributary, followed by station 23 at Piping River, a tributary. The mean NH₃-N concentration of the stations at the main river of the upper Baram River shows a decreasing trend from upstream to midstream area and an increasing trend from midstream to downstream area (Figure 35).

In addition, Appendix 21 shows that $\text{NH}_3\text{-N}$ classification of most of the stations from upstream to downstream area fall in Class III of NWQS for Malaysia. Meanwhile, only stations 11, 12, 14, 15, 16, 17, 18, 19, 20, and 29 in the year 2015 fall in Class II in the $\text{NH}_3\text{-N}$ classification (Appendix 21). Besides, four stations in year 2015 fall in Class IV of NWQS for Malaysia in the $\text{NH}_3\text{-N}$ classification (Appendix 21). Significantly higher mean $\text{NH}_3\text{-N}$ concentration was observed at stations 21, 22, 24, and 25 due to the surface runoff from the logging sites to the river during heavy rainfall. At station 30 observed relatively high $\text{NH}_3\text{-N}$ with the lowest DO concentration, relatively low nitrite and nitrate concentrations, which indicate that the $\text{NH}_3\text{-N}$ discharge from the longhouses do not have enough DO concentration to convert ammonia to nitrite and nitrate.

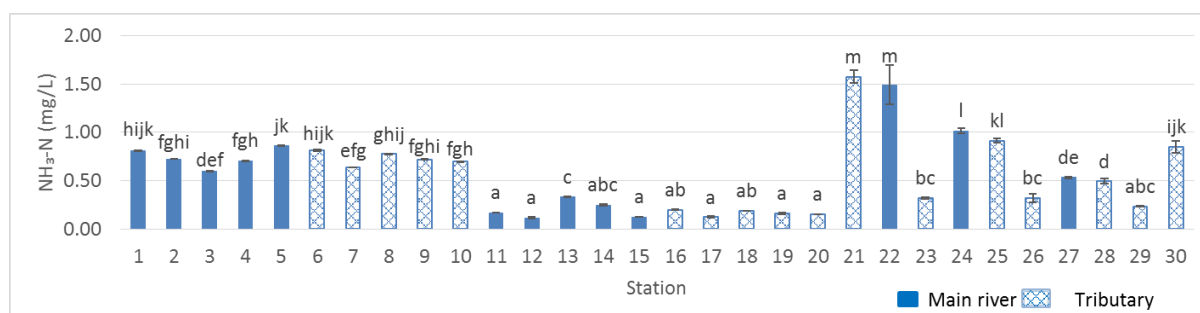


Figure 34: Mean $\text{NH}_3\text{-N}$ (mg/L) concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

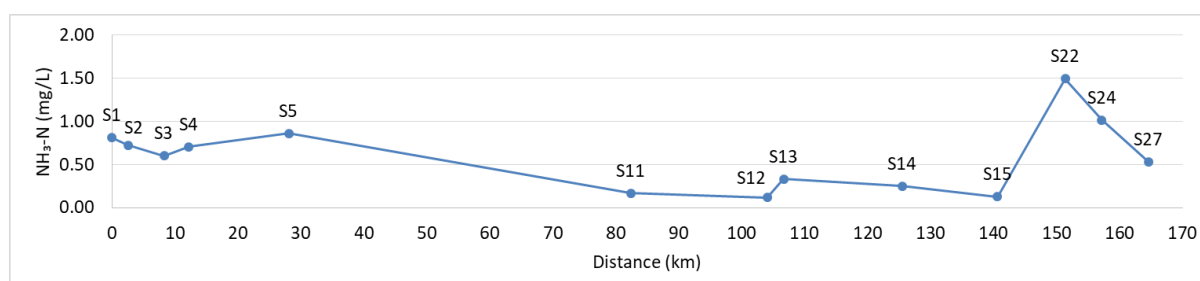


Figure 35: Mean $\text{NH}_3\text{-N}$ (mg/L) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.3.15 Organic-Nitrogen (Org-N)

Significantly higher mean Org-N concentration was observed at station 7 (2.74 mg/L) at Temedan River, a tributary, at the upstream area of the upper Baram River, followed by station 8 (2.31 mg/L) at Sebatu River, a tributary, as shown in Figure 36. Stations 7 and 8 were significantly higher in mean Org-N concentration than the other tributaries. Significantly lower mean Org-N concentration was observed at station 10 (1.02 mg/L) at Moh River, a tributary, than the other tributaries at the upstream area. The mean Org-N concentration of the stations at the midstream area of the upper Baram River was in the range of 0.46 to 1.66 mg/L (Figure 36). The highest mean Org-N concentration was at station 13 at the main river, downstream of longhouses at Long San. The second highest mean Org-N concentration was at station 15 (1.58 mg/L) at the main river, downstream of longhouses at Long Na'ah. Significantly lower in mean Org-N concentration was observed at station 17 at Lasa River, a tributary, than the other tributaries at the midstream area. The mean Org-N concentration of the stations at the downstream area of the upper Baram River ranged from 0.07 to 1.93 mg/L (Figure 36). Station 23 at Piping River, a tributary, was significantly higher in mean Org-N concentration than the other stations. Station 24 (0.82 mg/L) at the main river, downstream of the estuary of Tanan River, and station 30 at Kemenyeh River, a tributary, showed significantly higher mean Org-N concentration than the other stations at the downstream area. The lowest mean Org-N concentration was at station 25 at Jertang River, a tributary, followed by stations 26, 27 and 28. Stations 25, 26, 27, and 28 were significantly lower in mean Org-N concentration than the other stations (Figure 40). The mean Org-N concentration of the stations at the main river of the upper Baram River shows a decreasing trend from upstream to downstream area (Figure 37).

In addition, significantly lower mean Org-N concentration and higher mean NH₃-N were observed at stations 21 and 22. This was likely due to the decomposition of Org-N to NH₃-N under aerobic condition. At station 30, relatively low Org-N, high NH₃-N, low DO concentrations were observed, which indicate that DO being used up to convert Org-N to NH₃-N. Moreover, significantly higher mean Org-N concentration was observed at stations 2, 6, 7, 8, and 23. The high mean Org-N concentration of the stations was likely due to the waste disposal and surface runoff from the nearby longhouses and logging sites during heavy rainfall. In a study on organic matter, nutrients and trace metals of Serin River (Ling *et al.*, 2010c), it was reported that Org-N ranging from 0.24 to 3.90 mg/L were mainly contributed from the longhouses and human activities such as disposal of untreated waste and usage of fertilizer at their garden into the river.

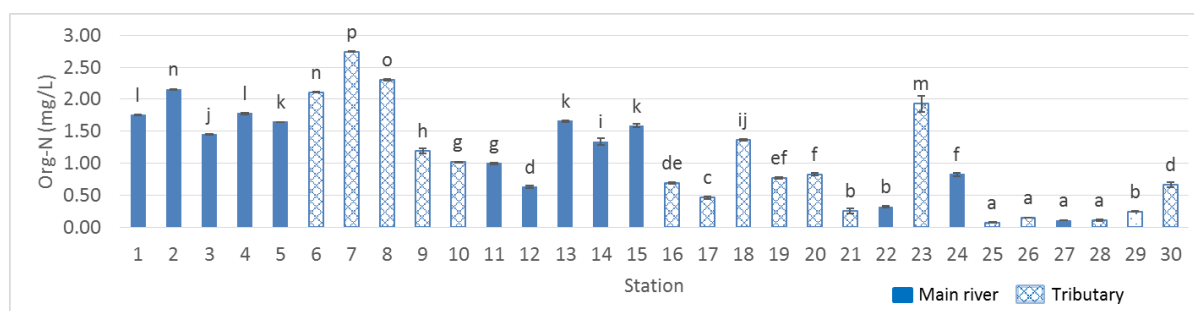


Figure 36: Mean Org-N (mg/L) concentration at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015 of the upper Baram River. Different letters show significant difference among the stations from upstream to downstream area ($p < 0.05$)

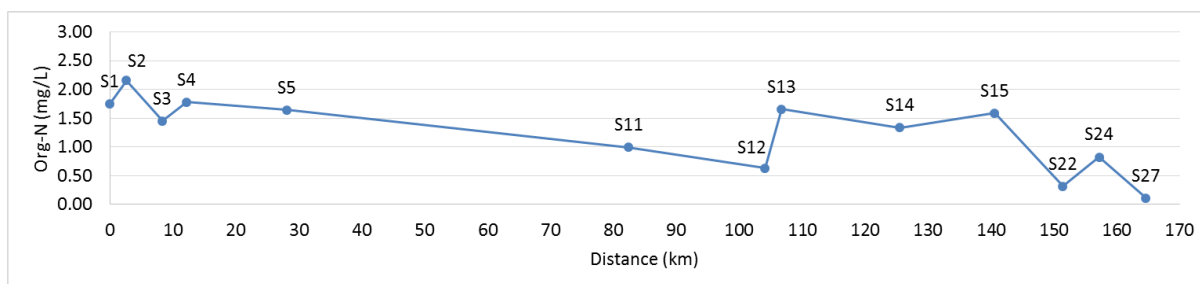


Figure 37: Mean Org-N (mg/L) concentration at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in the year 2015

3.3.4 Comparisons between different seasons

Results of the water quality study between with rainfall and no rainfall events at the downstream area at upper Baram River are arranged in the order of Jan 2015, to Jan 2016 and Mar 2016 as shown in Figures 38 to 67. In addition, the rainfall conditions were divided into three groups: with rainy, no rainy (El-Nino) and low or no rainy season. The Jan 2015 trip (652.8 mm) was grouped as “with rainy season”; Jan 2016 (70.6 mm) trip which coincided with El-Nino phenomena was grouped as “no rainy season”; and Mar 2016 (85.8 mm) trip was grouped as “low or no rainy season”.

3.3.4.1 Temperature

Overall, the mean temperature of the stations at the downstream area was significantly lower in value in Jan 2015 than in Jan and Mar 2016 (Table 3). Meanwhile, station 28 at Nakan River, a tributary, has significantly higher mean temperature than the other stations (Table 3). Figure 38 illustrates that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area have significantly different means among the three trips. Mean temperature of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016 varied from 23.77 to 29.73 °C (Figure 39). Station 22 at the main river, downstream of the estuary of Hit

River, in Jan 2015, has significantly lower mean temperature than the other stations (Figure 39). In addition, station 23 at Piping River, a tributary, and station 24 at the main river, downstream of the estuary of Tanan River, also have significantly lower mean temperature than the other stations (Figure 39). However, station 27 at the main river, next to longhouses at Long Kesseh, in Mar 2016, has significantly higher mean temperature than the other stations (Figure 39).

The highest temperature occurred when the water level was low as there was no rain one or two days before sampling in Jan and Mar 2016 which is confirmed by the rainfall data at Miri airport station, when there was no rainfall recorded two days before sampling (Appendix 18). From Appendix 18, it can be seen that the lowest daily total rainfall amount recorded was in Jan 2016 (70.6 mm), which coincided with El-Nino phenomena (MetMalaysia, 2017). Therefore, higher mean temperature was recorded during sampling in Jan and Mar 2016. On the contrary, there was rainfall recorded for a week prior the sampling at the upstream area (Appendix 18).

Table 3: Mean temperature (°C) of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Station	Mean Temperature (°C)			Mean
	Jan 2015	Jan 2016	Mar 2016	
22	23.77±0.06	28.29±0.01	29.03±0.01	27.03±0.01 ^a
23	24.07±0.06	25.70±0.01	25.83±0.01	25.20±0.01 ^b
24	24.07±0.06	27.86±0.01	29.11±0.01	27.01±0.01 ^a
25	25.07±0.06	26.33±0.01	27.91±0.01	26.43±0.01 ^c
26	25.47±0.06	26.46±0.01	27.18±0.01	26.37±0.01 ^d
27	24.27±0.06	28.13±0.01	29.73±0.01	27.38±0.01 ^e
28	27.33±0.06	27.61±0.01	29.27±0.01	28.07±0.01 ^f
Mean	24.86±0.01 ^A	27.19±0.01 ^B	28.30±0.01 ^C	

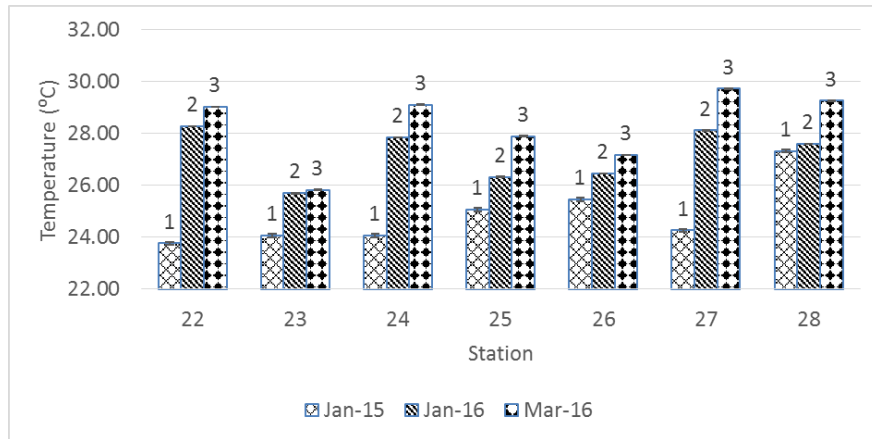


Figure 38: Mean temperature (°C) of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p<0.05$)

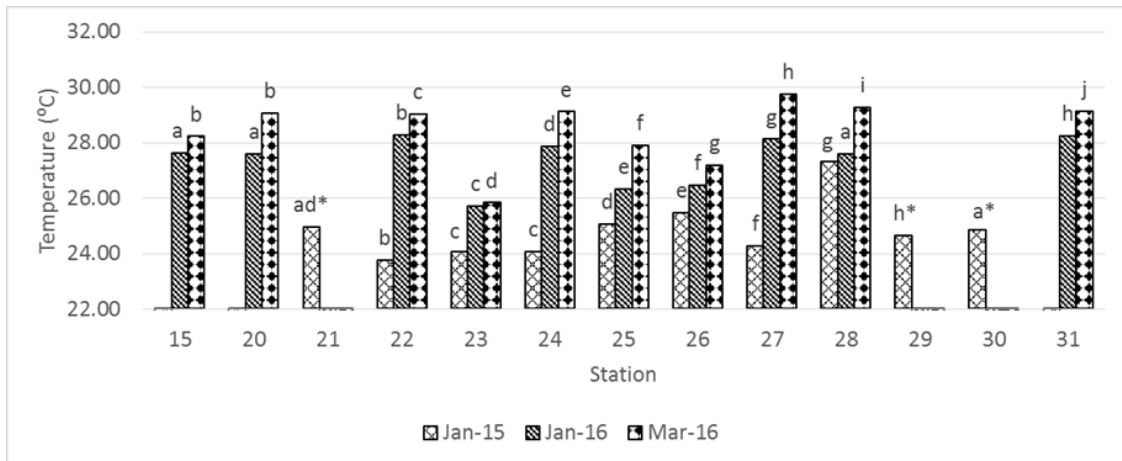


Figure 39: Mean temperature (°C) of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations on the same sampling date ($p<0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.2 DO

Overall, the mean DO concentration of the stations shows significantly lower DO concentration in Jan 2016 than in Jan 2015 and Mar 2016 (Table 4). Station 23 was significantly higher in mean DO concentration than the other stations (Table 4). However, station 22 at the main river, downstream of the estuary of Hit River, has significantly lower mean DO concentration than the other stations (Table 4). Figure 40 shows that all the repeated stations in Jan 2015, Jan and

Mar 2016 at the downstream area have significantly different means. From Figure 41, it can be seen that the mean DO concentration of the stations at the downstream area of the upper Baram River is in the range of 5.91 to 8.06 mg/L. Significantly higher mean DO concentration was observed at station 23 at Piping River, a tributary, in Mar 2016 (Figure 41). Besides, significantly lower mean DO concentration was observed at station 30 at Kemenyeh River, a tributary, in Jan 2015, followed by station 28 at Nakan River, a tributary, in Jan 2016, and station 31 at the main river, downstream of the estuary of Kemenyeh River (Figure 41).

From Appendix 22, it shows that DO at all the stations in Jan 2016 were classified under Class II, while in Mar 2016, only stations 15, 22 and 24 fall in Class II and the other stations fall in Class I of NWQS for Malaysia. In addition, the mean DO concentration of the stations was negatively correlated with pH ($r = -0.551$, $P = 0.000$, $n = 50$) as presented in Appendix 25.

Table 4: Mean DO concentration of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Station	Mean DO (mg/L)			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	6.90±0.01	6.14±0.01	6.78±0.00	6.61±0.00 ^a
23	6.97±0.01	6.46±0.00	8.06±0.01	7.16±0.00 ^b
24	7.59±0.01	6.13±0.00	6.69±0.00	6.80±0.00 ^c
25	6.34±0.01	6.32±0.01	7.62±0.00	6.76±0.00 ^d
26	6.53±0.01	6.15±0.01	7.69±0.00	6.79±0.00 ^d
27	7.32±0.01	6.07±0.00	7.32±0.00	6.91±0.00 ^e
28	6.50±0.01	6.02±0.00	7.45±0.00	6.66±0.00 ^c
Mean	6.88±0.00 ^A	6.19±0.00 ^B	7.37±0.00 ^C	

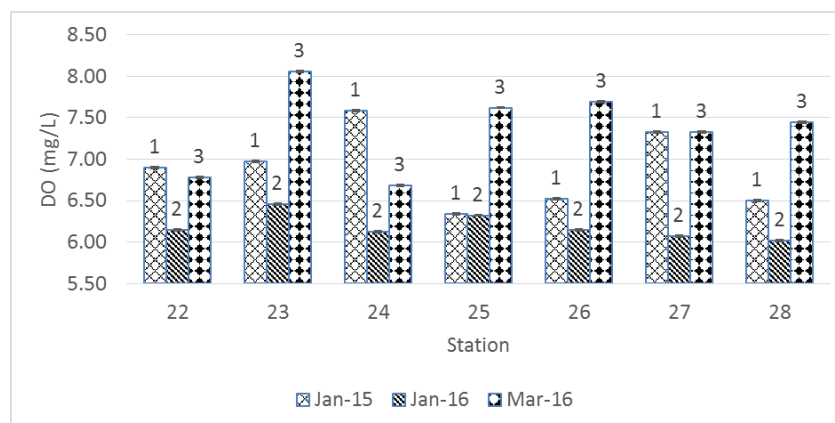


Figure 40: Mean DO (mg/L) concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

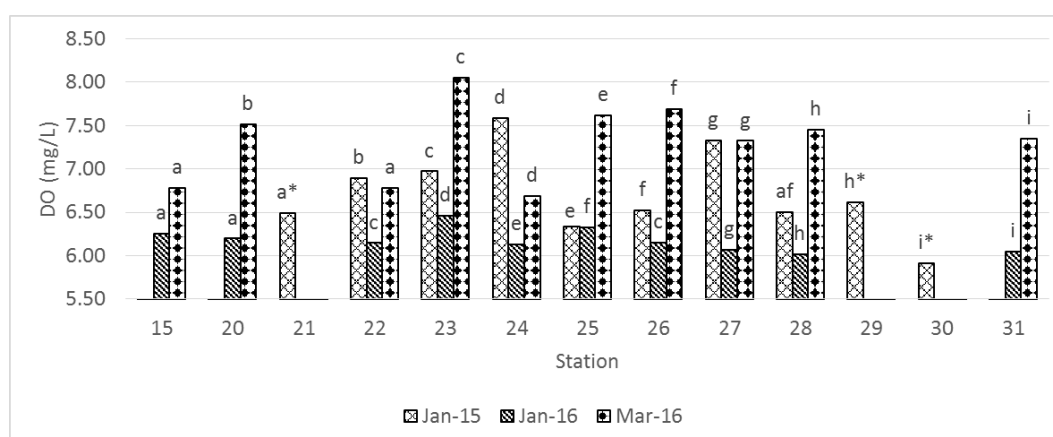


Figure 41: Mean DO (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.3 Specific conductance

In general, significantly lower mean specific conductance of the stations was observed in Jan 2015 than in Jan and Mar 2016 (Table 5). In addition, station 28 at Nakan River, a tributary, had significantly higher mean of three trips specific conductance than all the other stations (Table 5). Moreover, station 24 at the main river has significantly lower mean specific conductance than the other stations (Table 5). Figure 42 shows that all the repeated stations of the three trips at the downstream area have significantly different means within the same station, except for station 25. The mean specific conductance of the stations at the downstream area of

the upper Baram River ranged from 3.5 to 80.8 $\mu\text{S}/\text{cm}$ (Figure 43). In addition, station 29, Liyans River, a tributary, in Jan 2015, was significantly lower mean specific conductance than the other stations followed by station 24 (8.5 $\mu\text{S}/\text{cm}$) at the main river, downstream of the estuary of Tanan River, in the same month (Figure 43). On the contrary, station 28 in Jan and Mar 2016 showed significantly higher mean specific conductance than the other stations, followed by station 30 (Figure 43).

In addition, all the stations fall in Class I for pH value and specific conductance classification in both Jan and Mar 2016, except for stations 15 and 31 which fall in Class II in Mar 2016 for pH classification of NWQS for Malaysia (Appendix 22). The mean specific conductance was positively correlated with mean temperature ($r = 0.519$, $P = 0.000$, $n = 50$) as presented in Appendix 25.

Table 5: Mean specific conductance of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Station	Mean Specific Conductance ($\mu\text{S}/\text{cm}$)			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	22.4 $\pm$ 0.1	40.7 $\pm$ 0.0	40.8 $\pm$ 0.0	34.6 $\pm$ 0.0 ^a
23	48.3 $\pm$ 0.1	48.1 $\pm$ 0.0	51.9 $\pm$ 0.0	49.4 $\pm$ 0.0 ^b
24	8.5 $\pm$ 0.0	41.4 $\pm$ 0.0	41.4 $\pm$ 0.0	30.4 $\pm$ 0.0 ^c
25	41.0 $\pm$ 0.5	45.3 $\pm$ 0.0	44.8 $\pm$ 0.0	47.7 $\pm$ 0.0 ^d
26	54.0 $\pm$ 0.1	61.3 $\pm$ 0.0	44.9 $\pm$ 0.0	53.4 $\pm$ 0.0 ^e
27	3.5 $\pm$ 0.0	41.9 $\pm$ 0.0	48.0 $\pm$ 0.0	31.1 $\pm$ 0.0 ^f
28	76.3 $\pm$ 0.2	80.8 $\pm$ 0.0	79.6 $\pm$ 0.0	78.9 $\pm$ 0.0 ^g
Mean	36.3 $\pm$ 0.0 ^A	51.4 $\pm$ 0.0 ^B	50.2 $\pm$ 0.0 ^B	

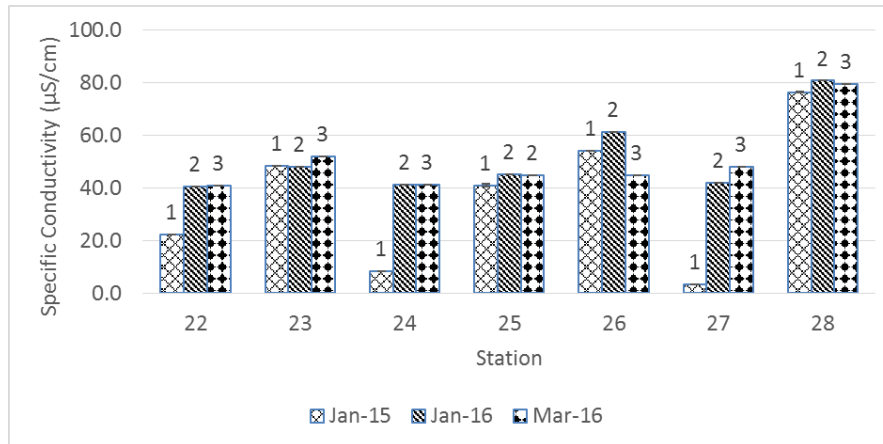


Figure 42: Mean specific conductance of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p<0.05$)

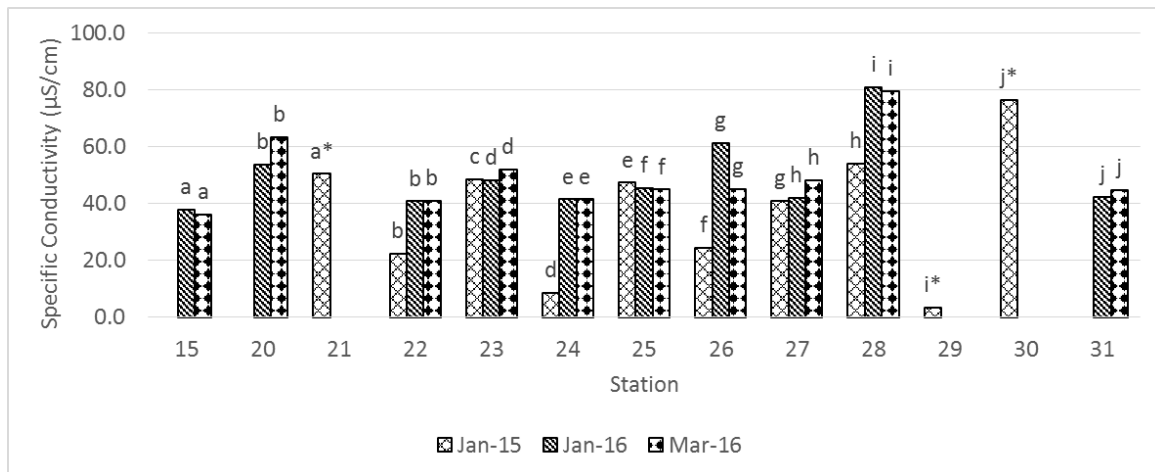


Figure 43: Mean specific conductance ($\mu\text{S/cm}$) of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p<0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.4 Water pH

Overall, the mean pH of the stations at the downstream area was significantly lower value in Mar 2016 than in Jan 2015 and Jan 2016 (Table 6). Meanwhile, station 24 at the main river, downstream the estuary of Tanan River, was significantly higher in mean pH than the other stations (Table 6). Besides, station 26 at Kesseh River, a tributary, was significantly lower in mean pH than the other stations. Figure 44 illustrates that all the repeated stations in Jan 2015,

Jan and Mar 2016 at the downstream area have significantly different means within the same station. Mean pH of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016 varied from 6.25 to 7.58 (Figure 45). Figure 45 shows that station 15 (pH 6.25) at the main river, downstream of longhouses at Long Na'ah, in Mar 2016, was significantly lower in mean pH than the other stations. In addition, station 31 at the main river, downstream of the estuary of Kemenyeh River, also showed significantly lower mean pH than the other stations (Figure 45). However, station 21 at Kahah River, a tributary, in Jan 2015, has significantly higher mean pH than the other stations, followed by station 23 in Jan 2016, station 24 in Jan 2015 and station 30 at Kemenyeh River, a tributary, in Jan 2015 (Figure 45).

Table 6: Mean pH of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Station	Mean pH			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	6.79±0.01	7.42±0.01	6.76±0.01	7.00±0.02 ^a
23	7.22±0.01	7.50±0.01	6.87±0.01	7.20±0.02 ^b
24	7.50±0.01	7.38±0.01	6.74±0.01	7.21±0.02 ^c
25	7.45±0.01	7.27±0.01	6.60±0.01	7.11±0.02 ^d
26	7.08±0.01	7.12±0.01	6.57±0.01	6.92±0.02 ^e
27	6.80±0.01	7.27±0.01	6.79±0.01	6.95±0.02 ^f
28	7.32±0.01	7.22±0.01	6.76±0.01	7.10±0.02 ^d
Mean	7.17±0.00 ^A	7.31±0.00 ^B	6.73±0.00 ^C	

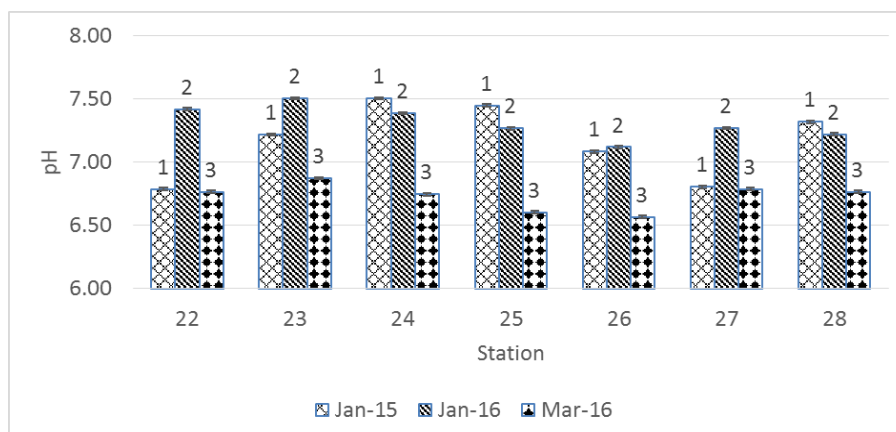


Figure 44: Mean pH of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

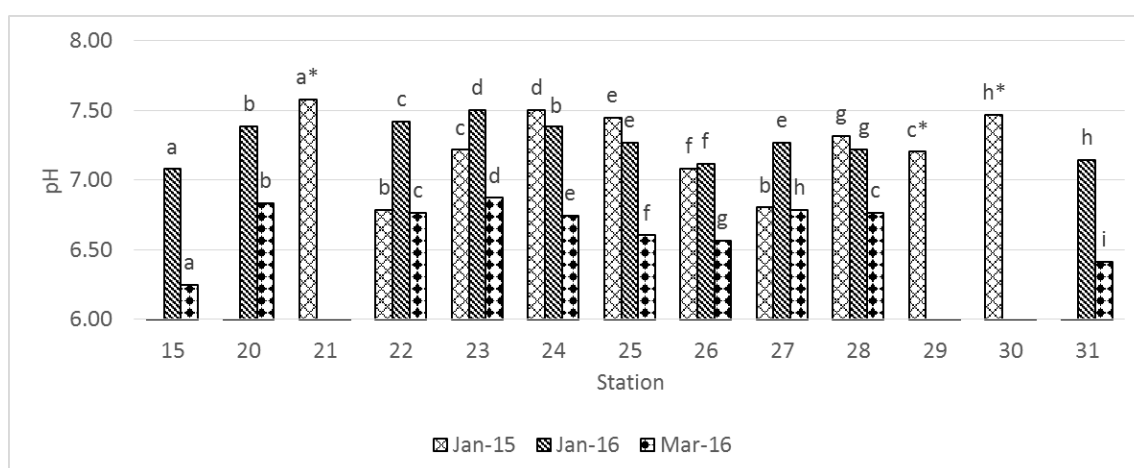


Figure 45: Mean pH value of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.5 Transparency

Overall, the mean transparency of the stations at the downstream area was significantly lower value in Mar 2016 than in Jan 2015 and Jan 2016 (Table 7). Meanwhile, station 22 at the main river, downstream of the estuary of Hit River, and station 27 at the main river, next to longhouses at Long Kesseh, have significantly lower mean transparency than the other stations (Table 7). Figure 46 illustrates that only stations 26 and 28, at the downstream area have

significantly different means within the same station for the three trips. Mean transparency of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016 varied from 0.04 to 1.10 m (Figure 47). The highest mean transparency was located at station 26 at Kesseh River, a tributary, in Jan 2016, followed by station 21 at Kahah River, and station 23 (1.05 m) at Piping River, and then station 28 (1.03 m) at Nakan River, a tributary, in Jan 2015 (Figure 47). Stations 21, 23, 26, and 28 have significantly higher mean transparency than the other stations. Station 28 (0.88 m), in Jan 2016 also has significantly higher mean transparency than the other stations (Figure 47). Station 22 (0.04 m) at the main river, downstream of the estuary of Hit River and station 31 (0.04 m) at the main river, downstream of the estuary of Kemenyeh River in Mar 2016 recorded the lowest mean transparency (Figure 47).

Table 7: Mean transparency of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Station	Mean Transparency (m)			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	0.06±0.01	0.18±0.01	0.04±0.00	0.10±0.01 ^a
23	1.05±0.01	0.30±0.01	0.30±0.01	0.14±0.01 ^b
24	0.08±0.01	0.14±0.01	0.05±0.01	0.55±0.01 ^c
25	0.15±0.01	0.15±0.10	0.11±0.01	0.58±0.01 ^c
26	0.51±0.01	1.10±0.01	0.11±0.01	0.17±0.01 ^b
27	0.08±0.01	0.36±0.01	0.08±0.01	0.09±0.01 ^a
28	1.03±0.06	0.88±0.01	0.07±0.01	0.66±0.01 ^d
Mean	0.42±0.01 ^A	0.45±0.01 ^A	0.11±0.01 ^B	

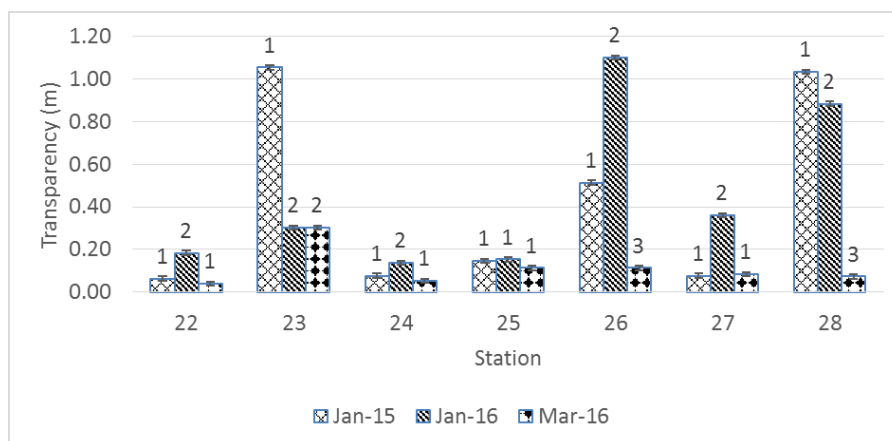


Figure 46: Mean transparency (m) of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

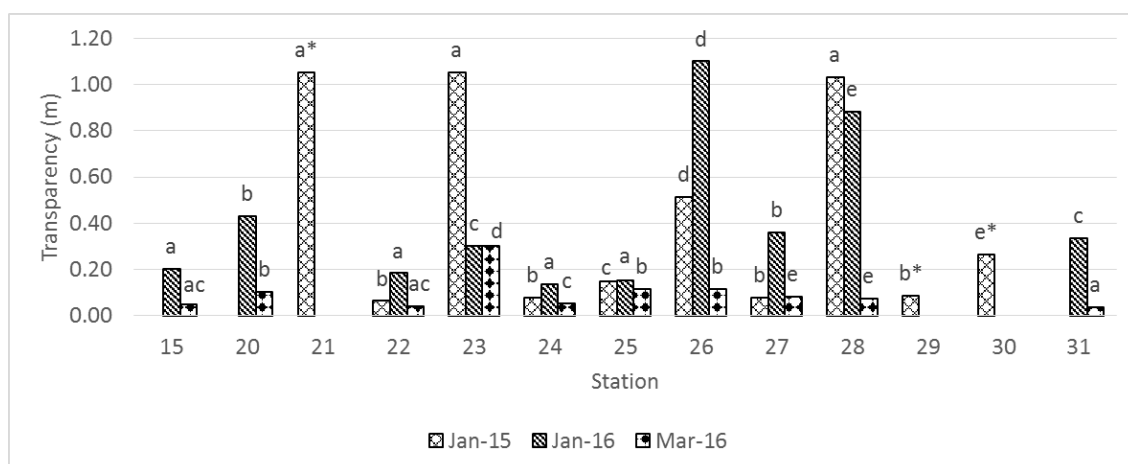


Figure 47: Mean transparency (m) of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.6 Turbidity

Overall, the mean turbidity in Jan 2016 was significantly lower than Jan 2015 and Mar 2016 (Table 8). Station 28 at Nakan River, a tributary, has significantly lower mean turbidity than the other stations (Table 8). Besides, station 22 at the main river, downstream of the estuary of Hit River, has significantly higher turbidity than the other stations (Table 8). Figure 48 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area have

significantly different means within the same station. The mean turbidity of the stations at the downstream area of the upper Baram River varied from 3.1 to 1091.5 NTU (Figure 49). Station 15 at the main river, downstream of Long Na'ah, in Mar 2016, has significantly higher mean turbidity than the other stations. In addition, station 22 (455.0 NTU) in Jan 2015, station 22 (632.7 NTU), 24 (656.1 NTU) and 31 (364.1 NTU), in Mar 2016 also have significantly higher mean turbidity than the other stations (Figure 49). Besides, station 26 at Kesseh River, a tributary, in Jan 2016, and station 23 (6.03 NTU) at Piping River, a tributary, in Mar 2016, had significantly lower mean turbidity than the other stations (Figure 49).

Moreover, turbidity of most of the stations in Jan 2016 were classified under Class II, except for stations 15, 22 and 24 which exceeded Class II and station 26 fall in Class I of NWQS for Malaysia (Appendix 22). The mean turbidity was negatively correlated with specific conductance ($r = -0.317$, $P = 0.025$, $n = 50$), pH ($r = -0.418$, $P = 0.003$, $n = 50$) and transparency ($r = -0.354$, $P = 0.003$, $n = 50$) as presented in Appendix 25.

Table 8: Mean turbidity of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Station	Mean Turbidity (NTU)			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	455±33	87±1	633±2	391±3 ^a
23	42±1	35±0	6±0	28±3 ^b
24	288±6	89±0	656±0	344±3 ^c
25	132±5	37±0	98±0	89±3 ^d
26	19±3	3±0	43±0	22±3 ^{bf}
27	291±16	27±0	120±0	146±3 ^e
28	9±1	17±0	13±0	13±3 ^f
Mean	178±2 ^{AB}	42±2 ^A	224±2 ^B	

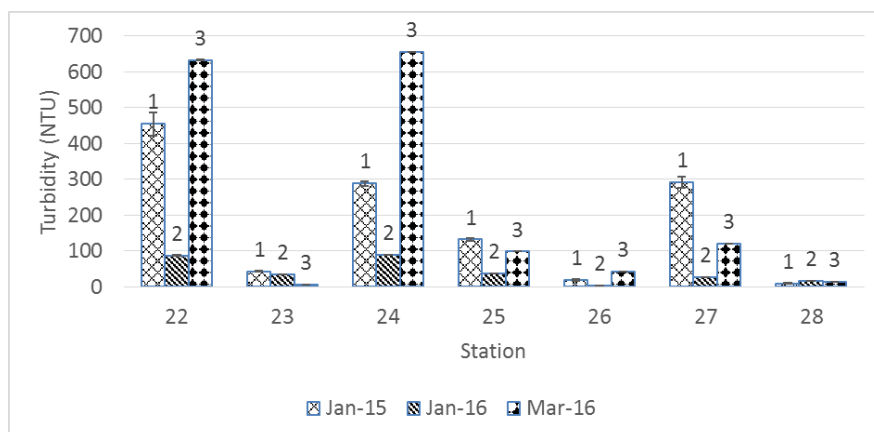


Figure 48: Mean turbidity of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

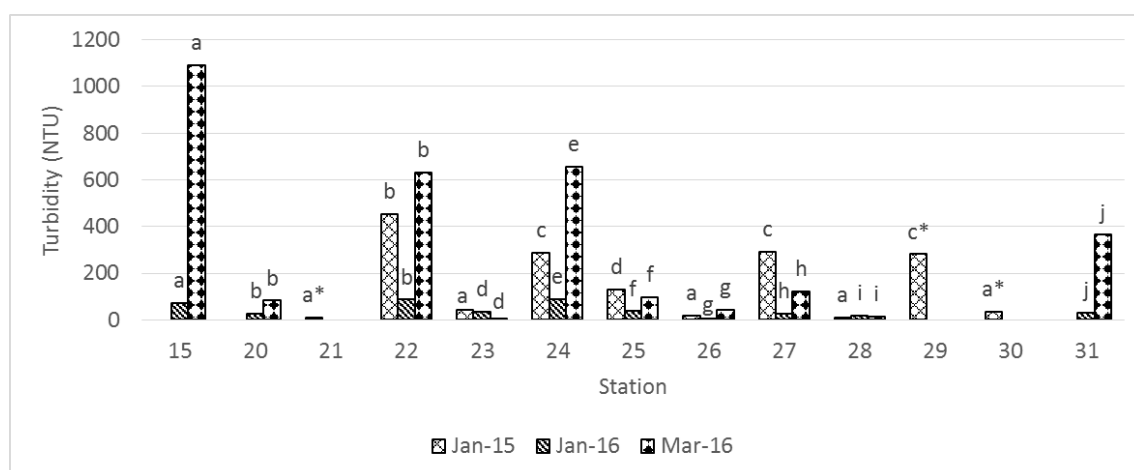


Figure 49: Mean turbidity (NTU) of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.7 TSS Concentration

In general, the mean TSS concentration of the stations was significantly higher in Mar 2016 than in Jan 2015 and Jan 2016 (Table 9). Station 22 at the main river, downstream of the estuary of Hit River, has significantly higher mean TSS concentration than the other stations (Table 9). The lowest TSS concentration was observed at station 28 at Nakan River, followed by stations 23 at Piping River, and 26 at Kesseh River (Table 9). Stations 23, 26 and 28 have significantly

lower mean TSS concentration than the other stations. Figure 50 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area have significantly different means within the same station, except stations 23, 26 and 28. Figure 51 shows that the mean TSS concentration of the stations was in the range of 5 to 1363 mg/L. Station 15 at the main river, downstream of longhouses at Long Na'ah, in Mar 2016, has significantly higher mean TSS concentration than the other stations, followed by station 22 (919 mg/L) at the main river, downstream of the estuary of Hit River and station 24 (789 mg/L) at the main river, downstream of the estuary of Tanan River, in Mar 2016 (Figure 51). On the other hand, station 26 at Kesseh River and station 28 at Nakan River, in Jan 2016 have significantly lower mean TSS concentration than the other stations (Figure 51).

In addition, for TSS classification, stations 26, 27, 28, and 31 in Jan 2016 fall in Class I (Appendix 22). Besides, stations 15, 20, 23, and 25 in Jan 2016 and stations 20, 23, 25, and 28 in Mar 2016 fall in Class II. Two stations in Jan 2016 and three stations in Mar 2016 fall in Class III and three stations in Mar 2016 fall in Class V respectively in TSS classification of NWQS for Malaysia (Appendix 22). The TSS concentration was positively correlated with turbidity ($r = 0.937$, $P = 0.000$, $n = 50$) but negatively correlated with pH ($r = -0.418$, $P = 0.003$, $n = 50$) and transparency ($r = -0.354$, $P = 0.012$, $n = 50$) as presented in Appendix 25. Rivers contained higher mean TSS concentration during raining season than dry season. This is supported by Douglas *et al.* (1992) in the study of the impacts of selective commercial logging on stream hydrology, chemistry and sediments loads in the Ulu Segama Rainforest, Sabah, Malaysia, which found that large storm produced high suspended sediment loads to the river from the logged lands. In the study of water quality index: an indicator of surface water pollution in eastern part of Peninsular Malaysia, Tungak River (Hossain *et al.*, 2013), it was

also found that high TSS concentration reached 2,170 mg/L was due to heavy rain as it was wet season.

Table 9: Mean TSS of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Station	Mean TSS (mg/L)			Mean
	Jan 2015	Jan 2016	Mar 2016	
22	246±45	84±4	919±17	416±4 ^a
23	40±9	36±1	31±6	36±5 ^b
24	267±20	53±4	789±7	370±6 ^c
25	97±1	27±1	49±2	58±7 ^d
26	7±1	5±1	57±3	23±8 ^b
27	232±13	21±1	133±5	128±9 ^e
28	6±1	8±0	44±2	19±10 ^b
Mean	128±3 ^{AB}	33±3 ^A	289±3 ^B	

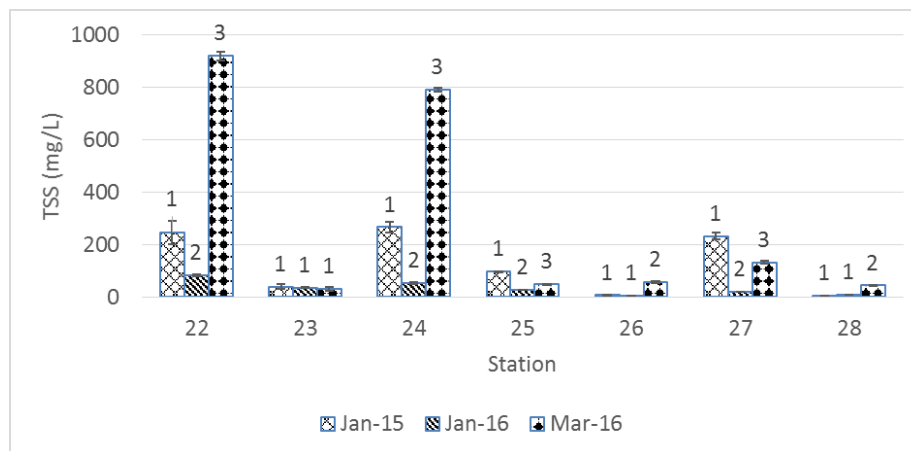


Figure 50: Mean TSS of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p<0.05$)

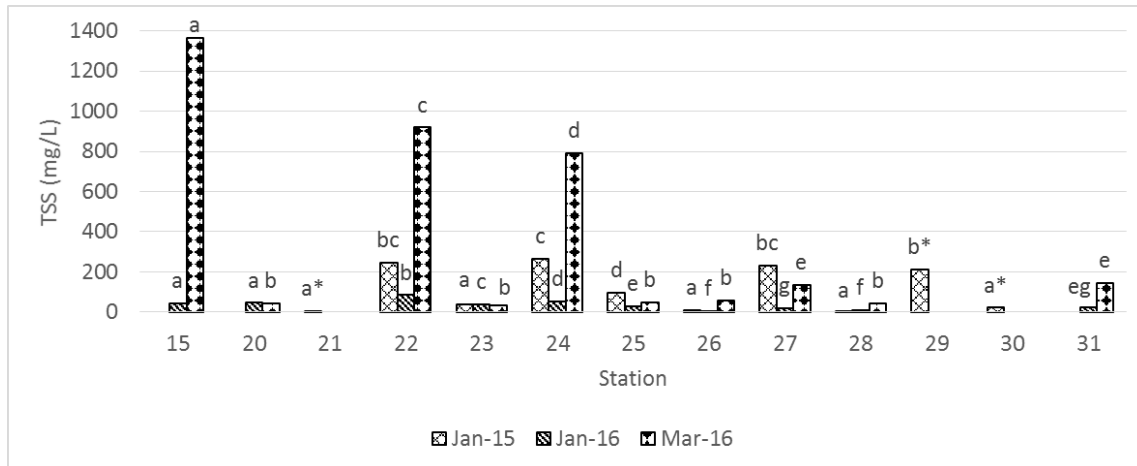


Figure 51: Mean TSS (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.8 Chl-*a* Concentration

The mean Chl-*a* concentration in Jan 2015 was significantly higher than in Jan and Mar 2016 (Table 10). Station 27 at the main river, next to longhouses at Long Kesseh, has significantly higher mean Chl-*a* concentration than the other stations (Table 10). The lowest mean Chl-*a* concentration was observed at station 23 at Piping River. Stations 23 and 25 have lower mean Chl-*a* concentration than the other stations (Table 10). Figure 52 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area have significantly different means within the same station, except stations 22 and 25. Based on Figure 53, it can be seen that the mean Chl-*a* concentration of the stations at the downstream area of the upper Baram River is in the range of 0.2 to 23.3 mg/m³. From Figure 53, station 25 at Jertang River in Jan 2016, recorded the lowest mean Chl-*a* concentration. Besides, the highest mean Chl-*a* concentration was recorded at station 29 at Liyans River, in Jan 2015, followed by station 27 at the main river, next to longhouses at Long Kesseh, in Jan 2015 and station 28 at Nakan River (Figure 53).

Stations 27, 28 and 29 have significantly higher mean Chl-*a* concentration than the other stations (Figure 53). The Chl-*a* concentration was negatively correlated with specific conductance ($r = -0.387$, $P = 0.005$, $n = 50$) as presented in Appendix 25.

Table 10: Mean Chl-*a* of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Station	Mean Chl- <i>a</i> (mg/m ³)			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	1.3±0.1	0.5±0.0	1.2±0.5	1.0±0.2 ^{ab}
23	0.3±0.0	0.4±0.0	0.7±0.0	0.5±0.2 ^a
24	1.1±0.3	0.4±0.0	3.0±0.1	1.5±0.2 ^b
25	0.2±0.1	0.2±0.0	2.0±0.1	0.8±0.2 ^a
26	1.7±0.1	0.7±0.1	0.5±0.1	1.0±0.2 ^{ab}
27	13.1±1.9	0.3±0.0	7.7±0.1	7.0±0.2 ^c
28	11.9±0.8	0.4±0.0	0.7±0.1	4.3±0.2 ^d
Mean	4.2±0.1 ^A	0.4±0.1 ^B	2.2±0.1 ^{AB}	

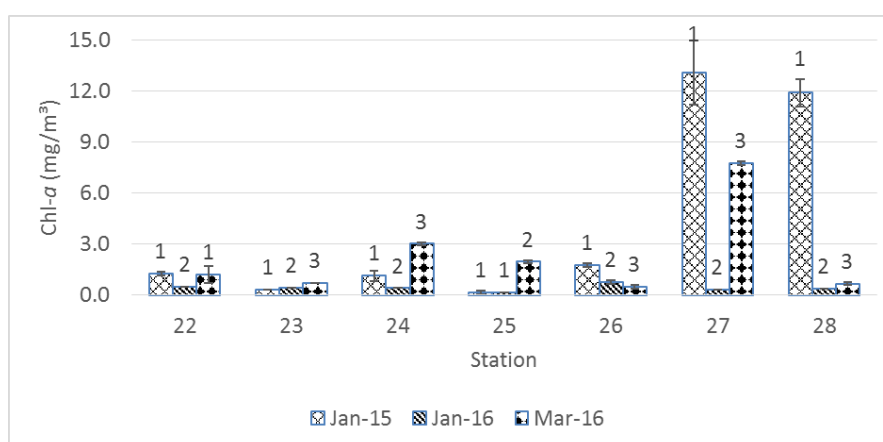


Figure 52: Mean Chl-*a* concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

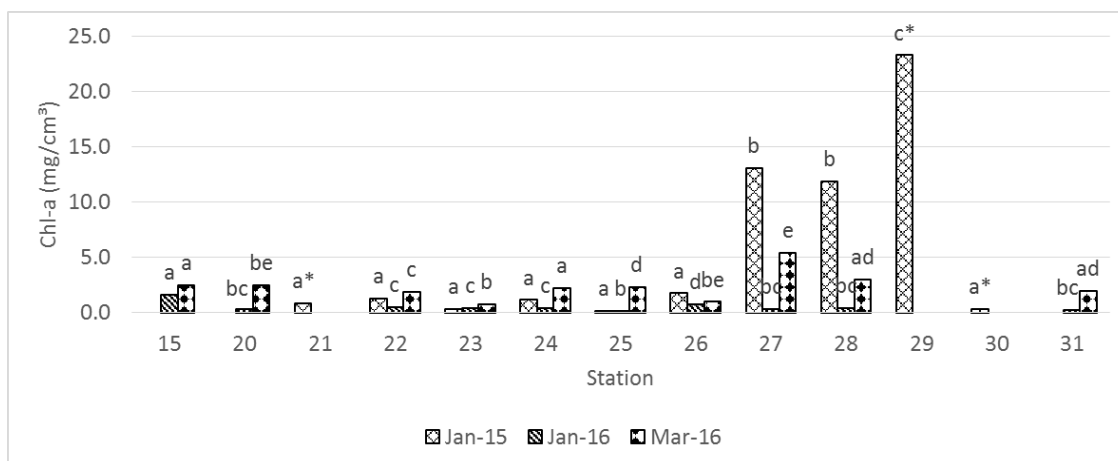


Figure 53: Mean Chl-*a* (mg/m³) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.9 BOD₅ Concentration

Significantly higher mean BOD₅ concentration was observed in Jan 2016 than Jan 2015 and Mar 2016 (Table 11). Station 22 at the main river, downstream of the estuary of Hit River recorded the highest mean BOD₅ concentration and was significantly higher in concentration than the other stations (Table 11). Figure 54 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area have significantly different means within the same station, except for station 25. Figure 55 illustrates that the mean BOD₅ concentration of the stations at the downstream area of the upper Baram River was in the range of 1.25 to 5.17 mg/L. Significantly higher mean BOD₅ concentration was observed at station 31 at the main river, downstream of the estuary of Kemenyeh River, followed by station 27 (4.83 mg/L) at the main river, next to longhouses at Long Kesseh, and station 28 (4.81 mg/L) at Nakan River, in Jan 2016 (Figure 55). Meanwhile, station 26, in Jan 2016 shows the lowest mean BOD₅ concentration (Figure 55). Furthermore, high mean BOD₅ concentration corresponded to low mean DO concentration. This is because higher DO needed for the decomposition of organic matter.

The BOD₅ concentration of the stations was negatively correlated with DO ($r = -0.308$, $P = 0.029$, $n = 50$) as presented in Appendix 25.

Table 11: Mean BOD₅ of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Station	Mean BOD ₅			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	2.48±0.02	4.05±0.06	4.53±0.06	3.69±0.03 ^a
23	2.20±0.04	4.26±0.03	2.97±0.15	3.14±0.03 ^b
24	1.96±0.04	2.72±0.05	3.70±0.26	2.79±0.03 ^c
25	2.60±0.03	2.61±0.03	3.10±0.10	2.77±0.03 ^c
26	1.25±0.03	4.33±0.03	3.07±0.06	2.88±0.03 ^c
27	2.11±0.03	4.83±0.05	2.83±0.23	3.26±0.03 ^b
28	1.92±0.03	4.81±0.02	3.13±0.06	3.29±0.03 ^d
Mean	2.08±0.02 ^A	3.94±0.02 ^B	3.33±0.02 ^C	

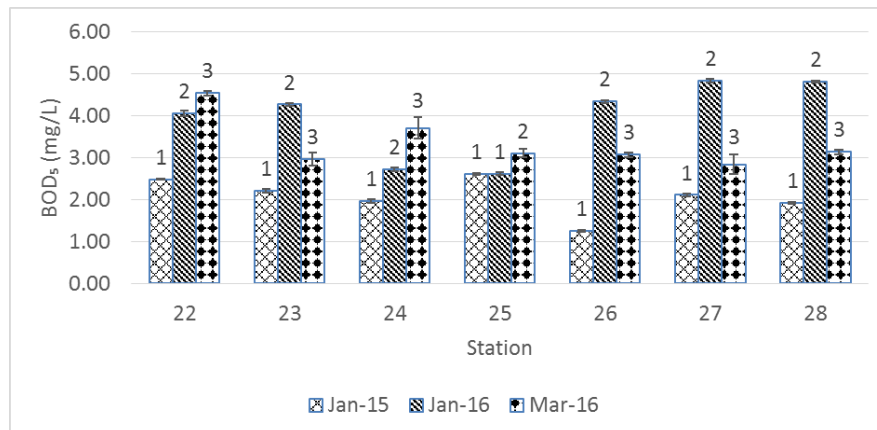


Figure 54: Mean BOD₅ concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

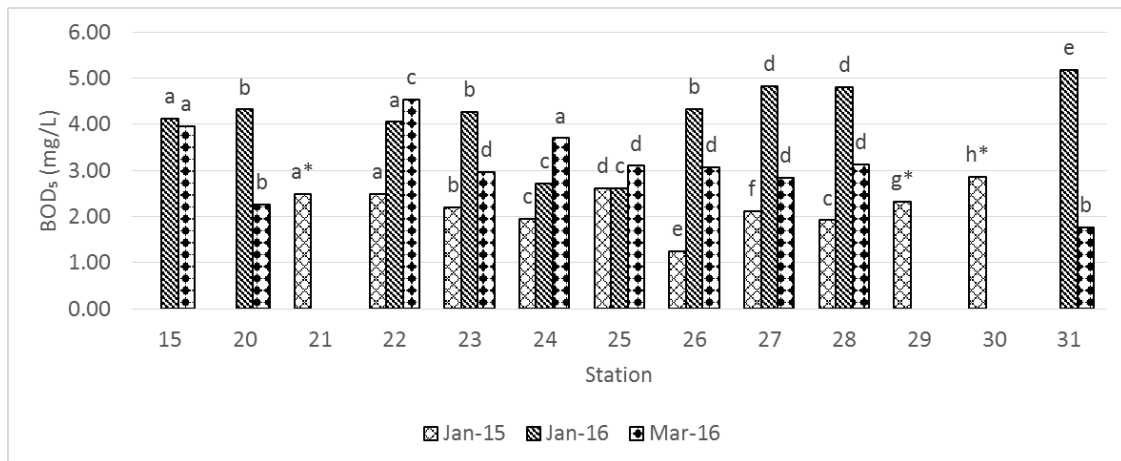


Figure 55: Mean BOD₅ (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.11 COD Concentration

In general, there is no significant difference in means among the mean COD concentration at different sampling dates (Table 12). Station 25 at Jertang River, has significantly higher mean COD concentration than the other stations (Table 12). Figure 56 shows that only stations 23 and 25 at the downstream area have significantly different means within the same station in Jan 2015, Jan and Mar 2016. Figure 57 illustrates that the mean COD concentration of the stations at the downstream area of the upper Baram River was in the range of 16 to 256 mg/L. Station 25 at Jertang River, recorded the highest mean COD concentration followed by station 30 at Kemenyeh River, in Jan 2015 and station 31 at the main river, downstream of the estuary of Kemenyeh River, in Jan 2016 and they have significantly higher mean COD concentration than the other stations (Figure 57). Besides, significantly lower mean COD concentration was observed at station 24 at the main river, downstream of the estuary of Tanan River (Figure 57).

Besides, for COD classification, station 24 in Jan 2016 fall in Class II while, the others in the year 2016 fall in Class III or IV of NWQS for Malaysia (Appendix 22). The COD of the stations was negatively correlated with DO ($r = -0.301$, $P = 0.033$, $n = 50$) and positively correlated with pH ($r = 0.335$, $P = 0.017$, $n = 50$) as presented in Appendix 25.

Table 12: Mean COD of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Station	Mean COD (mg/L)			
	Jan 2015	Jan 2016	Mar 2016	Mean
22	69±9	69±5	91±5	76±3 ^a
23	85±9	48±8	16±8	50±3 ^{bc}
24	32±8	16±8	99±5	49±3 ^{bc}
25	256±21	37±9	88±8	127±3 ^d
26	21±9	64±8	45±5	44±3 ^{be}
27	21±5	64±8	24±8	36±3 ^e
28	45±5	85±5	51±5	60±3 ^c
Mean	76±2 ^A	55±2 ^A	59±2 ^A	

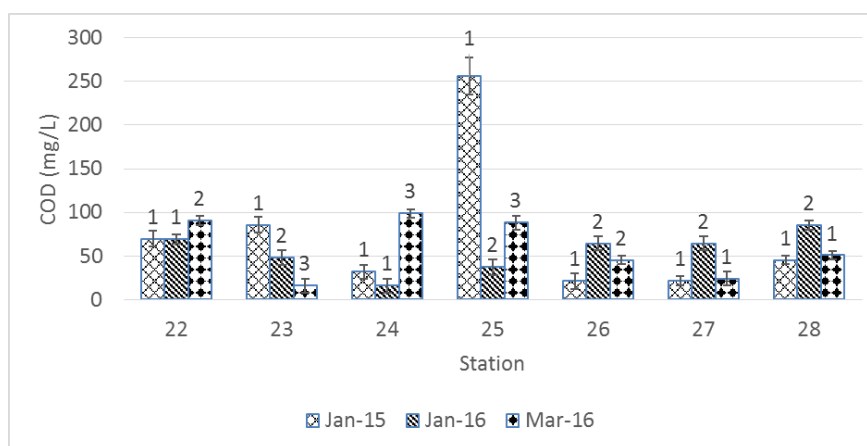


Figure 56: Mean COD concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

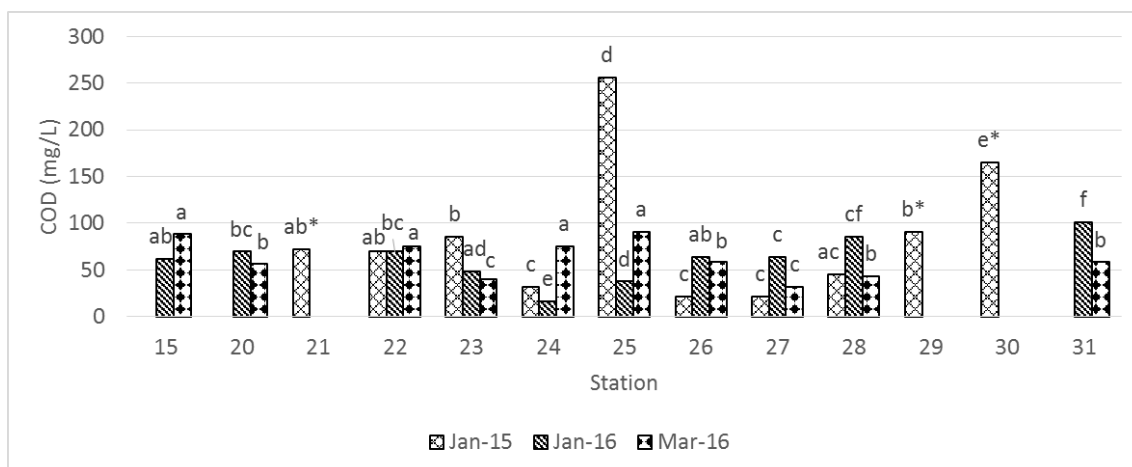


Figure 57: Mean COD (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.12 TP Concentration

In general, Jan 2016 has significantly higher mean TP concentration than Jan 2015 and Mar 2016 (Table 13). Station 23 at Piping River and station 28 at Nakan River have significantly higher mean TP concentration than the other stations (Table 13). Meanwhile, station 25 at Jertang River, a tributary has significantly lower mean TP concentration than the other stations (Table 13). Figure 58 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area showed significantly different means within the same station. Figure 59 illustrates that the mean TP concentration of the stations at the downstream area of the upper Baram River was in the range of 10.7 to 2087.4 $\mu\text{g/L}$. The lowest mean TP concentration of the stations at the downstream area was at station 25 at Jertang River, followed by station 24 at the main river, downstream of the estuary of Tanan River, in Jan 2015 and they were significantly lower in mean TP concentration than the other stations. The highest mean TP concentration was observed at station 23 at Piping River, and the second highest was at station 28 at Nakan River, in Jan 2016 and they were significantly higher in mean TP concentration than the other stations (Figure 59).

The mean TP concentration were significantly and positively correlated with BOD₅ ($r = 0.392$, $P = 0.005$, $n = 50$), NO₃-N ($r = 0.324$, $P = 0.024$, $n = 50$) and Org-N ($r = 0.354$, $P = 0.012$, $n = 50$) as presented in Appendix 25.

Table 13: Mean TP of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Date	Mean TP ($\mu\text{g/L}$)			Mean
	Jan 2015	Jan 2016	Mar 2016	
S22	486.0 $\pm$ 18.3	65.7 $\pm$ 0.3	750.6 $\pm$ 18.3	434.1 $\pm$ 3.0 ^a
S23	188.4 $\pm$ 1.9	2087.4 $\pm$ 18.1	880.7 $\pm$ 15.4	1052.2 $\pm$ 3.0 ^b
S24	19.6 $\pm$ 3.4	138.1 $\pm$ 3.9	227.0 $\pm$ 6.1	128.2 $\pm$ 3.0 ^c
S25	10.7 $\pm$ 0.3	62.8 $\pm$ 0.2	130.1 $\pm$ 2.0	67.9 $\pm$ 3.0 ^d
S26	41.6 $\pm$ 0.1	486.0 $\pm$ 18.3	161.7 $\pm$ 1.2	229.8 $\pm$ 3.0 ^e
S27	170.3 $\pm$ 0.9	213.0 $\pm$ 0.8	252.9 $\pm$ 0.4	212.0 $\pm$ 3.0 ^f
S28	114.7 $\pm$ 0.7	1851.2 $\pm$ 10.1	178.4 $\pm$ 2.3	714.8 $\pm$ 3.0 ^g
Mean	147.3 $\pm$ 2.0 ^A	700.6 $\pm$ 2.0 ^B	368.8 $\pm$ 2.0 ^{AB}	

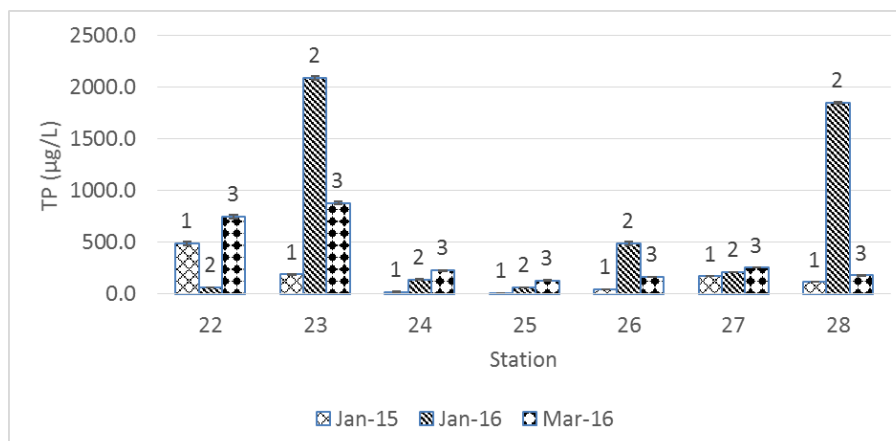


Figure 58: Mean TP concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

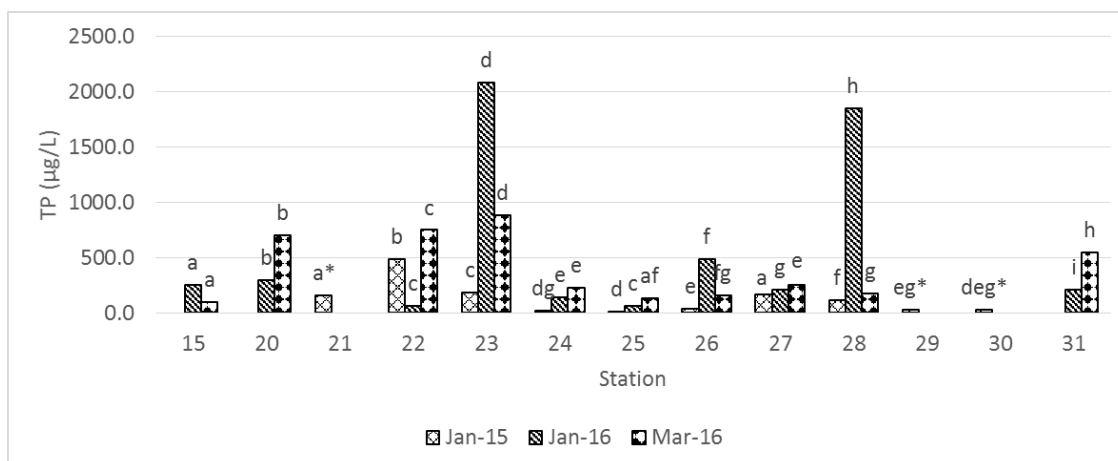


Figure 59: Mean TP ($\mu\text{g/L}$) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.13 $\text{NO}_2\text{-N}$ Concentration

Overall, the mean $\text{NO}_2\text{-N}$ concentration in Jan, 2016 was significantly lower in concentration than in Jan 2015 and Mar 2016 (Table 14). Station 27 at the main river, next to longhouses at Long Kesseh, has significantly higher mean $\text{NO}_2\text{-N}$ concentration than the other stations (Table 14). Figure 60 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area have significantly different means within the same station, except for stations 22 and 26. Figure 61 shows that the mean $\text{NO}_2\text{-N}$ concentration of the stations at the downstream area of the upper Baram River was in the range of 0.000 to 0.009 mg/L. The highest mean $\text{NO}_2\text{-N}$ concentration was at station 27 at the main river and the second highest mean $\text{NO}_2\text{-N}$ concentration was at station 31 (0.010 mg/L) at the main river, downstream of the estuary of Kemenyeh River, in Mar 2016 (Figure 61). Stations 27 and 31, in Mar 2016 have significantly higher mean $\text{NO}_2\text{-N}$ concentration than the other stations (Figure 61). Besides, significantly lower mean $\text{NO}_2\text{-N}$ concentration was observed at station 27, 28, and 31 (0.000 mg/L) in Jan 2016 than the other stations (Figure 61).

Table 14: Mean NO₂-N of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Mean NO ₂ -N (mg/L)				
Date	Jan 2015	Jan 2016	Mar 2016	Mean
S22	0.007±0.001	0.002±0.000	0.006±0.001	0.005±0.000 ^a
S23	0.006±0.001	0.002±0.001	0.001±0.001	0.003±0.000 ^b
S24	0.008±0.000	0.002±0.000	0.004±0.001	0.005±0.000 ^a
S25	0.009±0.001	0.001±0.001	0.004±0.001	0.004±0.000 ^a
S26	0.004±0.001	0.001±0.001	0.003±0.001	0.003±0.000 ^b
S27	0.005±0.001	0.000±0.000	0.015±0.001	0.007±0.000 ^c
S28	0.003±0.001	0.000±0.000	0.004±0.001	0.002±0.000 ^b
Mean	0.006±0.000 ^A	0.001±0.000 ^B	0.005±0.000 ^A	

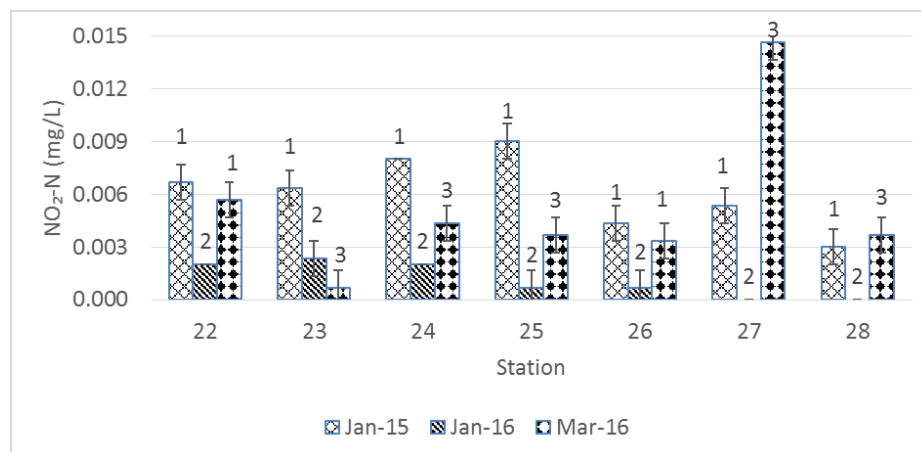


Figure 60: Mean NO₂-N concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p<0.05$)

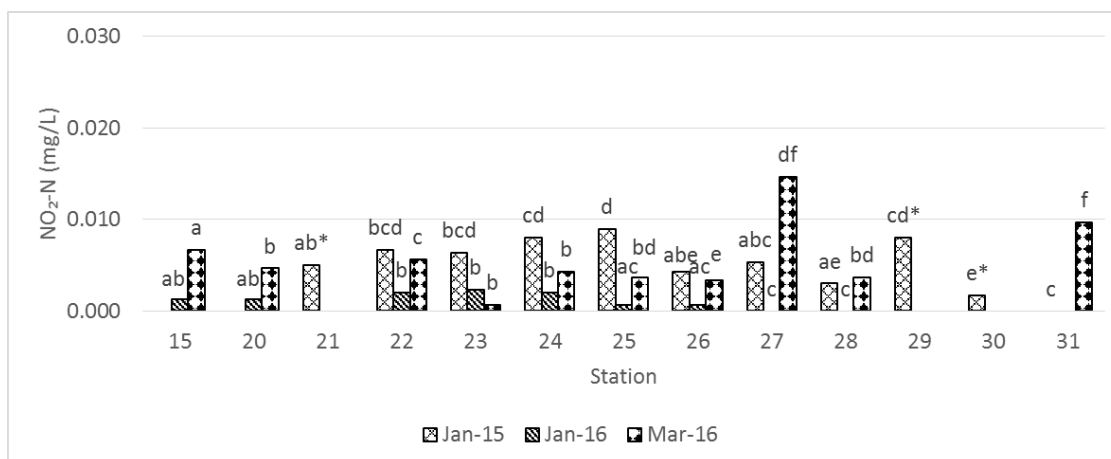


Figure 61: Mean $\text{NO}_2\text{-N}$ (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.14 $\text{NO}_3\text{-N}$ Concentration

In general, the mean $\text{NO}_3\text{-N}$ concentration was significantly higher in concentration in Mar 2016 than in Jan 2015 and Jan 2016 (Table 15). Station 23 at Piping River has significantly higher mean $\text{NO}_3\text{-N}$ concentration than the other stations, except for station 25 at Jertang River, a tributary (Table 15). Figure 62 shows that not all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area was significantly different within the same station. Figure 63 shows that the mean $\text{NO}_3\text{-N}$ concentration of the stations at the downstream area of the upper Baram River was in the range of 0.00 to 0.08 mg/L. The highest mean $\text{NO}_3\text{-N}$ concentration was observed at station 25 and the second highest mean $\text{NO}_3\text{-N}$ concentration was observed at stations 26 (0.06 mg/L) in Mar 2016 (Figure 63). Station 25 and 26 were significantly higher in mean $\text{NO}_3\text{-N}$ concentration than the other stations (Figure 63). Station 27 at the main river, next to longhouses at Long Kesseh and station 31 at the main river, downstream of the estuary of Kemenyeh River in Jan 2016, station 15 at the main river, and station 22 (0.00 mg/L) at the main river in Mar 2016 recorded the lowest mean $\text{NO}_3\text{-N}$ concentration (Figure 63). Stations 15, 22, 27, and 31 were significantly lower in mean $\text{NO}_3\text{-N}$ concentration than the other stations

(Figure 63). The NO₃-N concentration of the stations was positively correlated with DO ($r = 0.325$, $P = 0.021$, $n = 50$) and NO₂-N ($r = 0.334$, $P = 0.018$, $n = 50$) but negatively correlated with temperature ($r = -0.359$, $P = 0.011$, $n = 50$) as presented in Appendix 25.

Table 15: Mean NO₃-N of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p < 0.05$). Different small letters show significant difference within the stations ($p < 0.05$)

Date	Mean NO ₃ -N			
	Jan 2015	Jan 2016	Mar 2016	Mean
S22	0.02±0.01	0.02±0.01	0.00±0.00	0.01±0.00 ^a
S23	0.02±0.01	0.06±0.01	0.04±0.01	0.04±0.00 ^b
S24	0.02±0.01	0.03±0.01	0.01±0.00	0.02±0.00 ^c
S25	0.01±0.01	0.01±0.01	0.08±0.01	0.03±0.00 ^{bd}
S26	0.01±0.01	0.01±0.00	0.06±0.01	0.03±0.00 ^d
S27	0.01±0.01	0.00±0.00	0.02±0.01	0.01±0.00 ^a
S28	0.00±0.01	0.02±0.00	0.01±0.00	0.01±0.00 ^a
Mean	0.01±0.00 ^A	0.02±0.00 ^A	0.03±0.00 ^B	

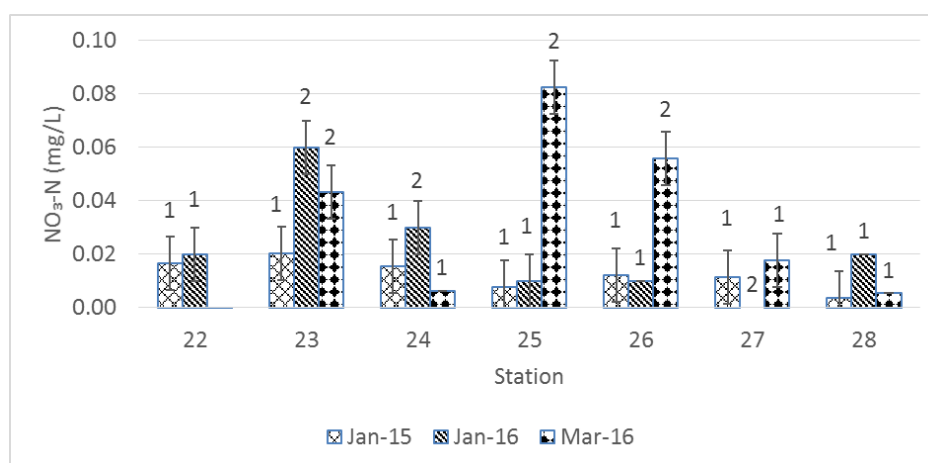


Figure 62: Mean NO₃-N concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p < 0.05$)

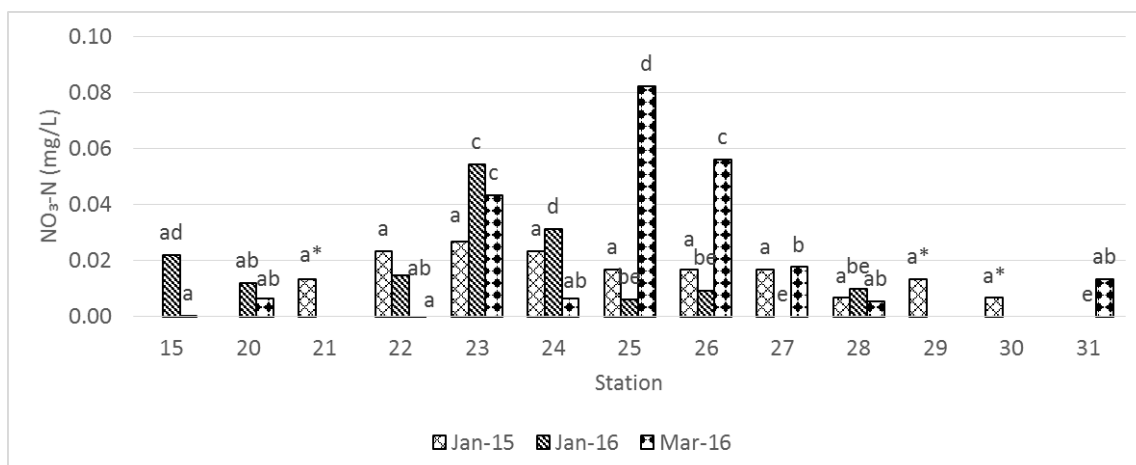


Figure 63: Mean NO₃-N (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.15 NH₃-N Concentration

In general, significantly higher mean NH₃-N concentration was observed in Jan 2015 than in Jan and Mar 2016 (Table 16). Station 22 has significantly higher mean NH₃-N concentration than the other stations (Table 16). Only stations 23, 24 and 25 in Jan 2015 showed significantly different means among all the three trips (Figure 64). Figure 65 illustrates that the mean NH₃-N concentration of the stations at the downstream area of the Baram River was in the range of 0.18 to 1.57 mg/L. Significantly higher mean NH₃-N concentration was observed at station 21 at Kahah River than the other stations, followed by station 25 at Jertang River in Jan 2015 (Figure 65). The lowest mean NH₃-N concentration was observed at stations 23 and 24 in Jan 2016 and they were significantly lower than the other stations (Figure 65). Based on Appendix 22, for the NH₃-N classification, most of the stations in the year 2016 fall in Class II of NWQS for Malaysia, except for the stations 22, 25, 26, 27, and 31 which fall in Class III. The mean NH₃-N concentration of the stations was negatively correlated with temperature ($r = -0.571$, $P = 0.000$, $n = 50$) as presented in Appendix 25.

Table 16: Mean NH₃-N of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Mean NH ₃ -N				
Date	Jan 2015	Jan 2016	Mar 2016	Mean
S22	1.49±0.20	0.31±0.00	0.27±0.00	0.69±0.02 ^a
S23	0.32±0.01	0.18±0.00	0.27±0.00	0.26±0.02 ^b
S24	1.01±0.03	0.18±0.01	0.24±0.00	0.48±0.02 ^c
S25	0.91±0.02	0.66±0.00	0.25±0.00	0.61±0.02 ^d
S26	0.32±0.04	0.38±0.00	0.25±0.01	0.32±0.02 ^b
S27	0.53±0.01	0.55±0.00	0.26±0.00	0.45±0.02 ^c
S28	0.49±0.03	0.22±0.00	0.25±0.00	0.32±0.02 ^b
Mean	0.73±0.01 ^A	0.35±0.01 ^B	0.26±0.01 ^B	

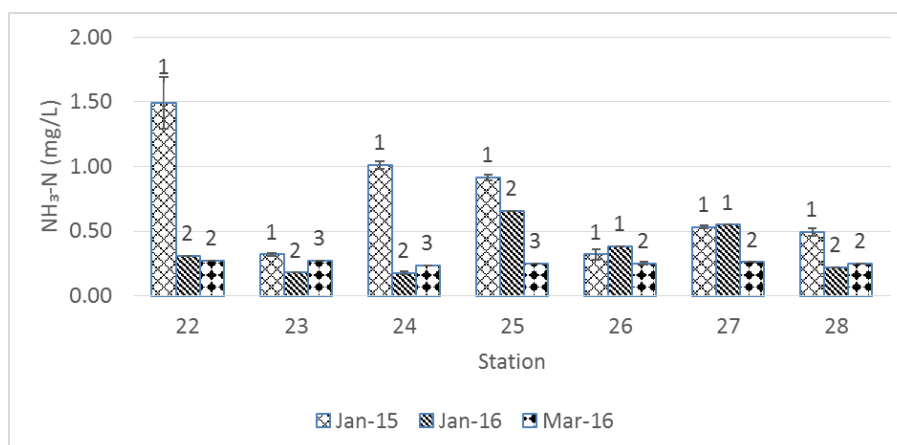


Figure 64: Mean NH₃-N concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p<0.05$)

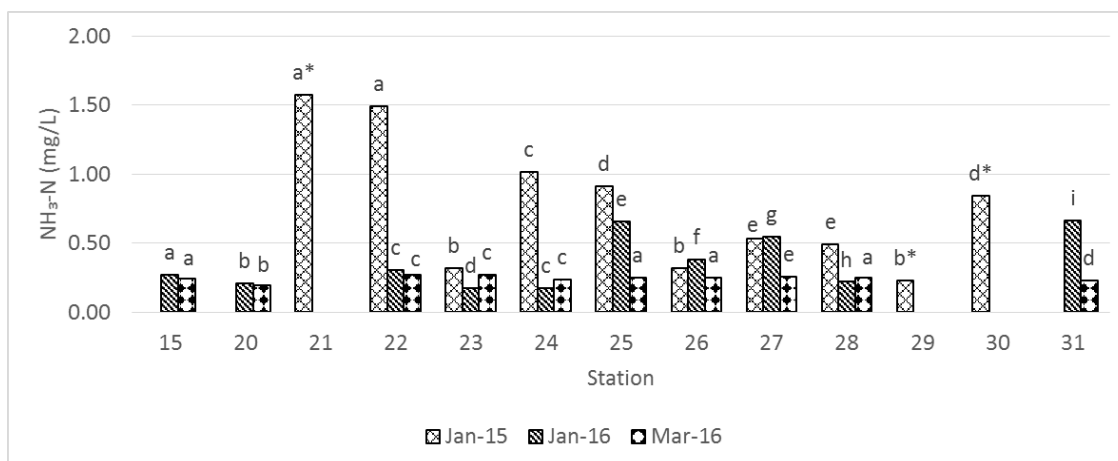


Figure 65: Mean NH₃-N (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p < 0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.3.4.16 Org-N Concentration

In general, all the three trips showed no significant difference (Table 17). Station 24 at the main river had significantly higher mean Org-N concentration than the other stations (Table 17). Figure 66 shows that all the repeated stations in Jan 2015, Jan and Mar 2016 at the downstream area showed significantly different means within the same station. From Figure 67, it can be seen that the mean Org-N concentration of the stations at the downstream area of the upper Baram River was in the range of 0.06 to 1.93 mg/L. Significantly higher mean Org-N concentration was observed at station 23 at Piping River, in Jan 2015, followed by station 31, in Jan 2016 then, stations 24 and 30 in Jan 2015 (Figure 67). Station 15 at the main river, downstream of longhouses at Long Naha'a, in Mar 2016, was significantly lower mean Org-N concentration than the other stations (Figure 67). The mean Org-N concentration of stations were positively correlated with NO₂-N ($r = 0.414$, $P = 0.003$, $n = 50$) and NO₃-N ($r = 0.410$, $P = 0.003$, $n = 50$) but negatively correlated with temperature ($r = -0.358$, $P = 0.011$, $n = 50$) and specific conductance ($r = -0.289$, $P = 0.042$, $n = 50$) as presented in Appendix 25.

Table 17: Mean Org-N of the stations at the downstream area of the upper Baram River, Sarawak. Different capital letters show significant difference among the different sampling date ($p<0.05$). Different small letters show significant difference within the stations ($p<0.05$)

Date	Mean Org-N			
	Jan 2015	Jan 2016	Mar 2016	Mean
S22	0.32±0.01	0.63±0.01	0.12±0.01	0.36±0.01 ^a
S23	1.93±0.13	0.41±0.01	0.20±0.00	0.85±0.01 ^b
S24	0.82±0.02	0.45±0.01	0.26±0.01	0.51±0.01 ^c
S25	0.07±0.01	0.64±0.01	0.28±0.01	0.33±0.01 ^{ad}
S26	0.15±0.01	0.50±0.00	0.22±0.00	0.29±0.01 ^{de}
S27	0.11±0.01	0.55±0.02	0.35±0.01	0.33±0.01 ^a
S28	0.11±0.02	0.40±0.01	0.34±0.00	0.28±0.01 ^e
Mean	0.50±0.01 ^A	0.51±0.01 ^A	0.25±0.01 ^A	

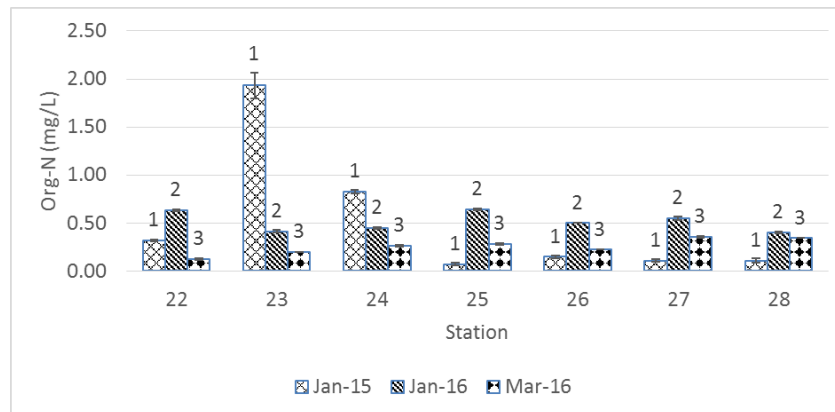


Figure 66: Mean NH₃-N concentration of the stations in Jan 2015, Jan and Mar 2016 at the downstream area of the upper Baram River, Sarawak. Different numbers show significant difference within the same station ($p<0.05$)

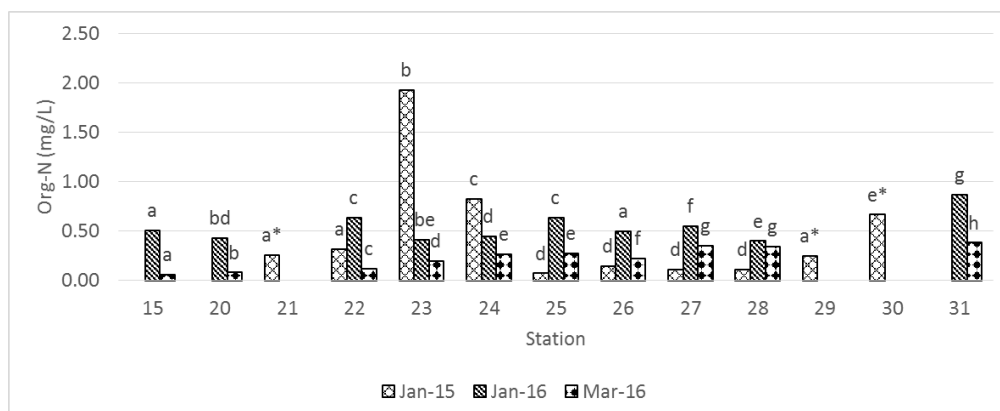


Figure 67: Mean Org-N (mg/L) concentration of the stations at the downstream area of the upper Baram River in Jan 2015, Jan and Mar 2016. Different letters show significant difference among the stations at the same sampling date ($p<0.05$). *Data of stations 21, 29 and 30 are not available in Jan and Mar 2016 due to inaccessibility

3.4 Comparison between the main river and tributaries

In summary, stations 16 and 17 were high in temperature, specific conductance, pH value and COD concentration. Meanwhile, station 30 was low in DO, Chl-*a*, NO₂-N and NO₃-N concentrations. Besides, stations 9, 18, 27, 29 were high in Chl-*a* concentration. Overall, the upstream area of the Baram River was high in BOD₅, TP, NO₂-N, NO₃-N, and Org-N concentrations. In addition, BOD₅ concentrations of the stations at the upstream area are significantly higher in Jan and Mar 2016 than in Jan 2015. On the other hand, the stations at the midstream area were high in COD concentration. Besides, the stations at the downstream area in Mar 2016 were low in pH, high in turbidity, TSS, and NH₃-N.

Table 18 shows the comparisons of the impacts of different land uses on the parameters of water quality of the upper Baram River, Sarawak. Based on this study, logging activities are associated with high temperature, low DO, high specific conductance, low pH, high turbidity, TSS, BOD₅, COD, and nutrients (TP, NO₂-N, NO₃-N, NH₃-N and Org-N concentrations) in the river. Moreover, nearby longhouses are associated with low pH, high turbidity, TSS, BOD₅, TP, NO₃-N and Org-N were observed in the river.

Table 18: Comparisons of the impacts of different land uses on the parameters of water quality of the upper Baram River, Sarawak

Activities	Logging	Longhouses	Logging and longhouses	No logging or longhouses
High temperature (> 28°C)	16, 17		18	
Low DO (<6.5 mg/L)	16, 25, 30			
High specific conductance	16, 17, 20, 21, 23, 25, 30		28	
Low pH (<6.9)	9, 22	27		10
High turbidity (>200 NTU)	20, 22, 24	27	14, 15	12, 29
High TSS (>200 mg/L)	20, 22, 24	27	14, 15	12, 29
High BOD ₅ (>4.00 mg/L)	9	3	1	8, 10
High COD (>120 mg/L)	25, 30		13, 14, 15	12
High TP (>1000 µg/L)	6, 7, 9	2, 4	1	
High NO ₂ -N (>0.02 mg/L)	6, 7, 20			
High NO ₃ -N (>0.04 mg/L)	7	4, 5		10
High NH ₃ -N (>1.00 mg/L)	21, 22			
High Org-N (>1.50 mg/L)	1, 6, 7, 23	2, 4, 5	13, 15	8

Table 19 shows that the range of parameter values at the stations of the main river and tributaries from upstream to downstream area at the upper Baram River, observed from Jan 2015 to Mar 2016 and the results of independent *t*-test to compare between the main river and tributaries. Overall, this study found that the means of specific conductance, transparency, Chl-*a*, and NO₂-N of the main river stations have significantly lower concentrations compared to tributaries (Table 21). Besides, the means of DO, turbidity and TSS of the stations at the main river showed significantly higher concentrations compared to tributaries (Table 21).

Table 19: Comparisons of the water quality parameters of the stations between the main river (n = 69) and tributaries (n = 81) from upstream to downstream area at the upper Baram River, Sarawak in 2015 and 2016

Parameters	Main river	Mean	Tributaries	Mean	<i>p</i> -value
Temperature (°C)	23.77-29.73	26.82	24.03-31.41	26.60	<i>p</i> >0.05
DO (mg/L)	6.05-7.59	6.64	5.91-6.97	6.48	<i>p</i> <0.05
Specific conductance (µS/cm)	8.5-50.0	34.5	3.5-79.6	49.7	<i>p</i> <0.05
pH	6.3-7.5	7.0	6.6-7.8	7.2	<i>p</i> >0.05
Turbidity (NTU)	7-1091	267	3-468	74	<i>p</i> <0.05
Transparency (m)	0.0-0.4	0.1	0.1-1.1	0.4	<i>p</i> <0.05
TSS (mg/L)	20-1363	262.7	5-320	56	<i>p</i> <0.05
Chl- <i>a</i> (mg/m ³)	0-13	3	0-25	5	<i>p</i> <0.05
BOD ₅ (mg/L)	1.8-5.7	3.5	1.3-4.8	3.0	<i>p</i> >0.05
COD (mg/L)	16-182	75	21-256	76	<i>p</i> >0.05
TP (µg/L)	19.6-2198.0	511.7	10.7-2087.4	458.1	<i>p</i> >0.05
NO ₂ -N (mg/L)	0.000-0.015	0.006	0.001-0.055	0.009	<i>p</i> <0.05
NO ₃ -N (mg/L)	0.00-0.07	0.02	0.01-0.09	0.02	<i>p</i> >0.05
NH ₃ -N (mg/L)	0.12-1.49	0.48	0.12-1.57	0.45	<i>p</i> >0.05
Org-N (mg/L)	0.11-2.15	0.89	0.07-2.74	0.76	<i>p</i> >0.05

3.5 Water Quality Index (WQI)

Figure 68 shows that the WQI of the water quality parameters of the stations from the upstream to downstream area at the main river of the Baram River in the year 2015. The WQI of the stations at the main river shows a decreasing trend from upstream to midstream area, except for station 5, and an increasing from midstream to downstream area.

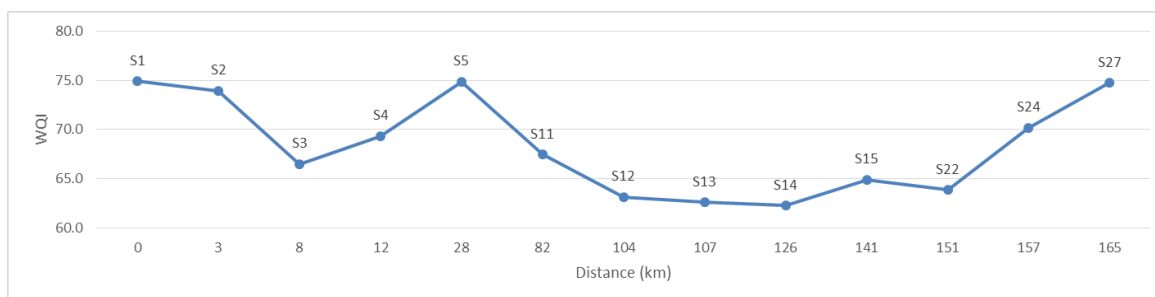


Figure 68: WQI of the stations at the main river from the upstream to downstream area of the upper Baram River, Sarawak in 2015

The water quality index (WQI) of the stations from the upstream to the downstream area at the upper Baram River ranged from 62.3 to 88.5 as shown in Table 20. According to the DOE's water quality classification based on WQI, the stations from the upstream to downstream area at Baram River in 2015, only station 26 (88.5) at Kesseh River, a tributary, and station 28 (82.9) at Nakan River, a tributary, were classified as "clean" in 2015, while the other stations were classified as "slightly polluted" in 2015 (Table 20). Station 26 (75.9) and 28 (74.7) were indicated as "slightly polluted" in Jan 2016. In addition, station 26 (88.5) was slightly improved in Mar 2016 (77.5) but still indicated as "slightly polluted" and station 28 (80.5) was indicated as "clean". On the other hand, WQI on the stations 22 and 25 became worsen after rainfall. WQI of station 22 changed from 63.9 during rainfall in Jan 2015 to 71.0 with no rainfall in Jan 2016 and 64.8 with no or low rainfall in Mar 2016. Meanwhile, WQI of station 25 changed from 64.8 during rainfall in Jan 2015 to 77.9 with no rainfall in Jan 2016 and 75.3 with no or low rainfall in Mar 2016.

The WQI of the stations at the downstream area of the upper Baram River ranged from 61.8 to 82.9 as shown in Table 21. According to the DOE's water quality classification based on WQI, for the stations at the downstream area in Jan 2016, only station 24 at the main river, downstream of the estuary of Tanan River was classified as "clean" and the other stations were classified as "slightly polluted" (Table 21). Meanwhile, for the stations at the downstream area in Mar 2016, only station 20 at Patah River, station 23 at Piping River, and station 28 at Nakan River were classified as "clean" and the other stations were classified as "slightly polluted" (Table 21).

Based on Tables 22 and 23, only stations 20 and 23 at the tributary, shows an increasing trend of WQI from Jan 2015 (slightly polluted), to Jan 2016 (slightly polluted), and then, Mar 2016 (clean). In addition, station 31, also shows an increasing trend from Jan to Mar 2016. Besides, stations 15, 22, 24 and 25 show an increasing trend of WQI from Jan 2015 to Jan 2016 and a decreasing trend from Jan 2016 to Mar 2016. Besides, stations 26, 27 and 28 show a decreasing trend of WQI from Jan 2015 to Jan 2016 and an increasing trend from Jan 2016 to Mar 2016.

Table 20: Sub Index (SI) and WQI of the means of DO, BOD, COD, TSS, NH₃-N, and pH of the stations from the upstream to the downstream area at the upper Baram River in 2015

	SIDO	SIBOD	SICOD	SISS	SIAN	SIpH	WQI	DOE Class	Class
July 2015									
1	91.46	73.73	57.35	70.38	56.56	98.84	74.9	III	Slightly polluted
2	89.87	74.32	50.39	73.31	55.83	99.13	74.0	III	Slightly polluted
3	91.09	74.45	19.61	56.95	54.20	99.23	66.5	III	Slightly polluted
4	90.48	81.31	52.62	30.29	58.45	99.54	69.3	III	Slightly polluted
5	87.53	78.70	50.39	79.50	53.05	99.35	74.9	III	Slightly polluted
6	89.53	79.24	59.86	36.27	51.71	99.28	69.8	III	Slightly polluted
7	90.18	83.14	67.98	29.15	56.29	99.20	71.5	III	Slightly polluted
8	90.88	76.39	44.18	37.94	59.63	99.52	68.5	III	Slightly polluted
9	91.35	81.13	48.24	38.12	55.71	99.27	69.6	III	Slightly polluted
10	91.87	67.43	26.58	58.87	53.20	98.74	66.5	III	Slightly polluted
September 2015									
11	90.47	86.42	13.89	28.38	83.01	99.19	67.4	III	Slightly polluted
12	91.22	77.79	0.00	21.69	88.33	98.13	63.1	III	Slightly polluted
13	91.25	81.18	5.11	25.39	69.35	98.48	62.6	III	Slightly polluted
14	91.19	80.72	6.23	17.90	74.47	98.78	62.3	III	Slightly polluted
15	90.58	81.93	13.07	15.00	87.42	98.40	64.9	III	Slightly polluted
16	92.59	80.23	6.81	90.13	79.71	95.34	74.5	III	Slightly polluted
17	94.96	88.89	16.54	89.40	87.66	94.10	79.2	II	Slightly polluted
18	93.56	89.74	16.54	77.93	80.81	97.51	76.6	II	Slightly polluted
19	93.60	89.57	23.96	83.42	83.66	96.68	78.9	II	Slightly polluted
20	91.52	89.66	22.78	14.88	84.45	93.97	67.1	III	Slightly polluted
January 2015									
21	100.00	84.95	30.38	94.12	36.03	96.01	75.0	III	Slightly polluted
22	100.00	85.03	31.91	19.52	37.45	98.91	63.9	III	Slightly polluted
23	100.00	86.76	23.56	76.55	69.86	98.57	76.8	II	Slightly polluted
24	100.00	88.28	61.04	17.96	47.65	96.66	70.2	III	Slightly polluted
25	100.00	84.28	0.00	55.56	50.24	97.12	64.8	III	Slightly polluted
26	100.00	92.66	72.83	93.15	69.87	99.12	88.5	II	Clean
27	100.00	87.34	72.83	20.72	61.98	99.00	74.7	III	Slightly polluted
28	100.00	88.51	48.74	93.92	63.35	98.01	82.9	II	Clean
29	100.00	86.02	21.18	22.66	75.99	98.63	68.6	III	Slightly polluted
30	94.00	82.70	1.07	85.47	52.12	96.96	69.7	III	Slightly polluted

Table 21: Sub Index (SI) and WQI of the means of DO, BOD, COD, TSS, NH₃-N, and pH of the stations at the downstream area of the upper Baram River in 2016

Station	SIDO	SIBOD	SICOD	SISS	SIAN	SIpH	WQI	DOE Class	Class
January 2016									
15	88.62	76.91	36.87	74.70	71.69	99.13	74.6	III	Slightly polluted
20	87.85	75.65	31.91	74.03	78.42	97.55	74.1	III	Slightly polluted
22	88.13	77.36	31.91	59.52	70.43	97.34	71.0	III	Slightly polluted
23	88.37	76.02	46.56	78.24	81.76	96.67	77.7	II	Slightly polluted
24	87.34	83.57	77.82	70.85	81.97	97.57	82.9	II	Clean
25	87.64	84.23	55.82	82.58	57.74	98.31	77.9	II	Slightly polluted
26	85.51	75.57	35.15	94.51	67.46	98.99	75.9	III	Slightly polluted
27	86.93	72.53	35.15	85.82	61.37	98.29	73.3	III	Slightly polluted
28	85.46	72.61	23.56	92.89	77.34	98.56	74.7	III	Slightly polluted
31	86.78	70.46	16.93	83.93	57.50	98.89	69.1	III	Slightly polluted
March 2016									
15	94.97	77.90	22.35	0.00	74.66	94.32	61.8	III	Slightly polluted
20	100.00	86.37	40.52	75.50	79.74	99.14	80.8	II	Clean
22	95.75	74.32	28.91	14.04	72.25	98.80	64.8	III	Slightly polluted
23	100.00	82.04	53.37	80.56	71.86	99.29	81.7	II	Clean
24	95.06	79.64	28.91	12.41	75.60	98.69	65.8	III	Slightly polluted
25	100.00	81.21	21.18	72.56	74.28	97.78	75.3	III	Slightly polluted
26	100.00	81.42	38.66	69.04	74.09	97.49	77.5	II	Slightly polluted
27	100.00	82.86	61.04	33.60	73.18	98.91	75.7	III	Slightly polluted
28	100.00	81.00	51.01	74.47	74.26	98.80	80.5	II	Clean
31	100.00	89.46	39.12	31.55	76.21	96.14	73.3	III	Slightly polluted

3.6 Principal Component Analysis (PCA)

Table 22 shows the loadings of the first five varimax rotated factor analysis of the water quality parameters. All the data used were standardized before running PCA analysis. Component 1, which explains 25.7 % of total variance has strong positive loadings on TS, Turbidity and TSS, and moderate loadings on $\text{NO}_2\text{-N}$, whereas, it has moderate negative loadings on transparency, specific conductance and pH (Table 22). This component is likely interpreted as soil erosion which is the result of anthropogenic activities such as logging activities. In addition, component 2 has strong positive loadings on $\text{NO}_3\text{-N}$ and the moderate positive loadings on Org-N and TAN, whereas, it has strong negative loading on temperature and moderate negative loadings on $\text{NO}_2\text{-N}$, and it accounted for 17.2 % of the total variance (Table 22). This component likely represents the partially waste disposal activities from nearby settlement. Furthermore, component 3, which accounted for 10.91 % of the total variation, was found to have moderate positive loadings on pH and COD and moderate negative loading on DO (Table 22). This component likely represents the anthropogenic pollution area sources with high level of organic matter that consumes large amount of oxygen. In addition, component 4 has strong positive loading on BOD_5 and moderate loading on TP, which explains 10.76 % of the total variance (Table 22). This component likely represents the partially treated waste discharged from the sewage treatment plant from the surrounding residents. Besides, component 5, which explains 8.51 % of the total variance has negative loading on TAN and weak and positive loadings on temperature and Org-N (Table 22). This component likely represents the runoff from agricultural field which used organic nitrogen-based fertilizers.

Table 22: Loadings of the first five Varimax Rotated factor analysis of water quality parameters (n=50)

Parameter	Component				
	1	2	3	4	5
Turbidity	0.885				
TSS	0.848	-0.316			
Transparency	-0.673				-0.344
Specific conductance	-0.589	-0.343	-0.350		
NO ₂ -N	0.516	0.418			0.368
Chl- <i>a</i>	0.422				
Temperature		-0.729	-0.314		0.404
NO ₃ -N		0.713			0.377
Org-N		0.647		0.311	0.443
TAN		0.554			-0.548
pH	-0.513		0.637		
DO	0.466		-0.602	-0.388	
COD		-0.410	0.559		
BOD ₅				0.871	
TP		0.433	-0.431	0.581	
Eigenvalues	4.118	2.746	1.746	1.722	1.361
% Total Variance	25.737	17.163	10.913	10.76	8.505
Cumulative %	25.737	42.9	53.812	64.572	73.078

3.7 Loading of the Pollutants

Table 23 shows the loading of the pollutants of the stations at the main river of upper Baram River. Based on the Table 23, loading of all the potential pollutants (TSS, BOD₅, COD, TP, NO₂-N, NO₃-N, NH₃-N, and Org-N) showed a gradual increasing trend from upstream to downstream area. The flow rate of all the stations is shown in Appendices 19 and 20. Table 24 shows the loading of the potential pollutants from the 17 tributaries into the main river at the upper Baram River.

From Table 23, it can be seen that, TSS loading ranged from 742,938 to 51,936,460 kg/day and there was an increase of 25,610,674 kg/day of TSS loading from upstream to the downstream area at the main river in 2015. Total loading of TSS from the 17 tributaries was 8,919,839 kg/day (Table 24). Station 8, Sebatu River and station 20, Patah River contributed the highest and the second highest loading of TSS (Table 23). In addition, BOD₅ loading is in the range of 36,284 to 933,442 kg/day and there was an increase of 508,777 kg/day of BOD₅ loading from upstream to the downstream area at the main river in 2015 (Table 23). Total loading of BOD₅ from the 17 tributaries was 275,177 kg/day (Table 24). Station 8 and 9, Sela'an River contributed the highest and the second highest loading of TSS, BOD₅ to the river (Table 23). Besides, loading of COD ranged from 332,006 to 42,586,336 kg/day and there was an increase of 22,726,577 kg/day of COD loading from upstream to the downstream area at the main river in 2015 (Table 23). Total loading of COD from the 17 tributaries was 6,698,456 kg/day in 2015 (Table 24). Stations 8 and 18, Akah River contributed the highest and the second highest loading of COD to the river (Table 23).

Table 23 shows that the loadings of TP in the range of 3,485 to 175,758 kg/day and there was an increase of 22,683 kg/day of TP loading from upstream to the downstream area at the main river in 2015. A total of 41,180 kg/day from the tributaries was added to the river in 2015 (Table 24). Station 9 contributed the highest loading of TP to the river (Table 23). Moreover, the loadings of NO₂-N and NO₃-N of the stations at the main river ranged from 22 to 944 kg/day and 248 to 3,839 kg/day respectively (Table 23) and a total of 839 kg/day and 1,510 kg/day from the 17 tributaries were added to the downstream area of Baram River respectively (Table 24) in 2015. Station 17, Lasa River was the highest contributor for both of the loading of NO₂-N and NO₃-N.

In addition, the loading of $\text{NH}_3\text{-N}$ was in the range of 5,496 to 54,725 kg/day and a total of 34,041 kg/day was added to the downstream area of Baram River in 2015 (Table 23). Station 18 contributed the highest loading of $\text{NH}_3\text{-N}$ to the river (Table 24). Furthermore, the loading on Org-N was in the range of 19,107 to 272,524 kg/day and there was an increase of 253,417 kg/day of Org-N loading from upstream to the downstream area at the main river in 2015 (Table 23). A total of 48,841 kg/day from the tributaries was added to the river in 2015 (Table 24). Station 8 at the tributaries contributed the highest loading of Org-N followed by stations 10, Moh River, 17 and 9 (Table 24).

Furthermore, loading of the potential pollutants at the main river in Jan 2016 were observed lower than the loading in Jan 2015, while, loading of potential pollutants in Mar 2016 were observed higher than in Jan 2016 (Table 25). TSS loading in 2016 ranged from 346,865 to 358,323,492 kg/day (Table 23). A total of 574,232 and 25,490,231 kg/day from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24). The loading of BOD_5 ranged from 35,876 to 1,042,555 kg/day in 2016 (Table 23). A total of 43,636 and 155,360 kg/day from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24). The loading of COD ranged from 211,095 to 23,128,949 kg/day in 2016 (Table 23). A total of 659,454 and 2,910,051 kg/day from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24). The loading of TP was in the range of 1,007 to 83,591 kg/day in 2016 (Table 23). A total of 1,774 and 23,051 kg/day from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24).

The loadings on $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ of the stations at the main river in 2016 ranged from 9 to 1,752 kg/day and 38 to 751 kg/day respectively (Table 23). A total of 4 and 211 kg/day loadings on $\text{NO}_2\text{-N}$ from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24). Besides, a total of 47 and 1,232 kg/day of $\text{NO}_3\text{-N}$ loading from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24). In addition, the loading on $\text{NH}_3\text{-N}$ concentration was in the range of 1,428 to 64,674 kg/day in 2016 (Table 23). A total of 7,877 and 10,174 kg/day of $\text{NH}_3\text{-N}$ loading from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24). Furthermore, the loading of Org-N was in the range of 1,590 to 16,164 kg/day in 2016 (Table 23). A total of 9,669 and 11,543 kg/day of Org-N loading from the tributaries were added to the main river from Jan and Mar 2016 respectively (Table 24).

There is no significance different on the loadings from the tributaries under three different rainfall conditions, except for loading on $\text{NO}_3\text{-N}$, Jan 2015 and Jan 2016 are significantly lower than Mar 2016.

Table 23: Loading of the pollutants of the stations at the main river of upper Baram River, Sarawak

Loading (kg/day)								
Station	TSS	BOD ₅	COD	TP	NO ₂ -N	NO ₃ -N	NH ₃ -N	Org-N
Jul-Sep-Jan 2015								
1	936,522	62,183	863,130	17,457	80	284	8,818	19,107
2	1,555,335	44,350	654,423	14,751	180	437	10,310	30,698
3	1,472,151	56,244	683,034	10,289	183	352	8,038	19,392
4	2,081,678	36,284	332,006	28,597	152	932	9,169	23,130
5	1,876,357	59,633	526,022	11,871	127	1,036	13,648	26,047
11	742,938	85,668	966,886	30,264	550	342	18,124	47,045
12	3,755,886	84,981	1,005,576	31,794	944	1,847	15,677	67,599
13	1,844,019	90,454	1,892,482	3,485	187	681	15,515	46,236
14	3,027,333	292,001	2,794,240	78,908	451	2,555	46,366	76,716
15	2,222,730	190,576	1,470,529	12,083	659	3,595	28,653	41,860
22	5,676,217	74,531	3,632,779	24,017	22	308	5,496	32,832
24	51,936,460	933,442	42,586,336	175,758	78	3,827	27,160	147,538
27	26,547,196	570,960	23,589,707	40,141	329	3,839	54,725	272,524
Jan 2016								
15	755,599	71,085	1,057,839	4,354	23	379	4,732	8,752
22	510,763	48,672	781,166	3,339	15	135	2,369	4,792
24	1,283,193	62,025	1,061,550	1,007	31	225	4,679	9,688
27	346,865	41,065	462,487	20,113	22	524	1,720	3,981
31	697,368	35,876	211,095	1,822	26	413	2,328	5,901
Mar 2016								
15	358,323,492	1,042,555	23,128,949	25,547	1,752	88	64,674	16,164
22	4,979,664	268,744	6,639,552	83,591	553	751	23,442	9,397
24	38,569,383	190,282	3,134,054	31,505	238	(56)	11,295	5,065
27	407,761	38,883	524,264	11,542	9	568	3,575	2,566
31	4,751,746	22,286	449,743	1,367	26	38	1,428	1,590

Table 24: Loading of the pollutants from the tributaries of Baram River, Sarawak

Loading of the pollutants from the tributaries of Barak River, Barakkar								
Station	TSS	BOD ₅	COD	TP	NO ₃ -N	NO ₃ -N	NH ₃ -N	Org-N
Jul-Sep-Jan 2015								
6	101,116	11,660	131,596	4,119	4	80	752	4,055
7	357,613	8,091	95,745	3,027	23	60	292	3,715
8	1,085,260	53,235	1,113,781	2,051	87	256	2,336	8,130
9	741,602	71,531	684,502	19,330	42	337	1,930	7,292
10	302,722	25,955	200,277	1,646	64	123	1,051	7,631
16	23,847	313	15,262	101	1	4	22	106
17	2,001,312	35,969	1,641,016	6,773	500	289	1,380	7,466
18	1,801,501	38,745	1,600,804	2,724	56	149	17,566	2,838
19	913,806	12,088	472,241	396	23	80	5,095	1,085
20	907,893	8,531	322,095	432	18	76	914	5,522
21	5,269	1,356	56,443	81	3	10	422	343
23	8,538	1,134	62,446	60	5	10	557	43
25	17,566	825	49,056	102	2	8	153	70
26	18,182	1,255	60,633	34	4	12	382	77
28	552,422	2,995	150,259	103	5	12	850	184
29	1,563	688	19,857	43	2	4	64	68
30	79,628	804	22,443	157	1	2	274	215
Total	8,919,839	275,177	6,698,456	41,180	839	1,510	34,041	48,841
Jan 2016								
20	126,621	12,066	193,655	828	2	17	1,840	1,781
23	215,675	10,425	178,422	169	2	24	981	1,279
25	4,115	487	5,486	239	-	-	63	63
26	30,668	1,578	9,283	80	-	6	128	231
28	197,154	19,080	272,608	458	-	-	4,865	6,315
Total	574,232	43,636	659,454	1,774	4	47	7,877	9,669
Mar 2016								
20	168,903	9,115	225,204	2,835	15	331	1,004	1,110
23	17,304,829	85,373	1,406,148	14,135	63	1,055	4,738	4,126
25	116,321	11,092	149,555	3,293	55	66	973	1,312
26	7,684,105	36,040	727,284	2,211	36	52	2,435	3,306
28	216,073	13,740	401,859	577	43	59	1,025	1,689
Total	25,490,231	155,360	2,910,051	23,051	211	1,563	10,174	11,543

CHAPTER 4

SEDIMENT CHARACTERISTICS

4.1 Introduction

Sediment is important in a river because in aquatic system, sediment usually act as a storage of nutrients in water and an exchange of nutrients in the biological cycle (Nasolkar *et al.*, 1996; Walling *et al.*, 2003). The three main particle fractions of sediment are clay, silt and sand (National Academy of Sciences, 2016; Winterwerp & Kesteren, 2004; Bittelli *et al.*, 1999; Gee & Bauder, 1986). It is transported by river flow in the forms of suspended load and bed load (Wang *et al.*, 2015). Besides, human activities such as deforestation and crop farming enhance erosion thus increased sediment loads in natural river (Meade, 1996; Wei *et al.*, 2011). Furthermore, runoff from agricultural land under livestock farming often associated with the inputs from fertilizers and pesticide which delivery large quantities of mineral particles such as silt into the river network (Mcmellin *et al.*, 2002). The large quantities of minerals entering the water have harmful effects on the aquatic community. Besides, sediments were consistent sinks for NO_3^- and O_2 and the source of NH_4^+ (Trimmer *et al.*, 1998). Logging activities and oil palm plantation at the Baram River, increase soil erosion and introduce massive quantities of sediment into the river. Therefore, it is important to determine the sediment characteristics of the Baram River, Sarawak, Malaysia, in order to determine the status. The parameters of sediment characteristics studied at the Baram River includes pH analysis, organic matter analysis, particle size distribution (PSA), total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and total phosphorus (TP).

4.2 Materials and Methods

4.2.1 Study Area and Sampling Stations

This study was conducted at the upper Baram River, above Long Lama, Sarawak. A total of 30 stations were selected for the study of sediment characteristics. Table 1 (Chapter 3) shows the sampling stations with GPS location and description of the stations. Table 2 (Chapter 3) shows the sampling date and weather condition at the upstream, midstream and downstream area. Figure 5 (Chapter 3) shows the sampling stations location (Stations 1 to 30) at upper Baram River, Sarawak.

4.2.3 Preparation and Sample Collection

All the glassware and apparatus were soaked in HNO₃ solution, 10% and then rinsed three times with tap water followed by distilled water. Equipment was rinsed with distilled water before use. Sediment samples were collected by using fiber comp trowel. The submerged sample was collected at the site of the river. Double layered plastic bags were used to keep sediments. The sediment analyses were done approximately two weeks after the sampling. Three replicates were done for each analysis, except for PSA of the sediment. Two replicates were done for PSA of the sediment.

4.2.4 Ex-Situ Analyses

4.2.4.1 Sediment pH Analysis

The pH analysis of sediment was conducted according to Thomas (1996). A glass electrode pH Meter (Eutech, pH 700) was used to determine the pH value of the sediment. The pH meter was calibrated with pH value of 7 followed by pH 4 or 10. A sample with 10.0 g of air-dried sediment was weighed and transferred into a 50 mL beaker. A volume of 10 mL deionized water was added into the beaker in a ratio of 1:1. The suspension was stirred and mixed well. The suspension was left to stand for 10 minutes. Then, the electrode of pH meter was inserted into the suspension. The electrode was placed in the clear supernatant above the sediment. The reading of pH value was recorded. The electrode was rinsed with distilled water before each reading.

4.2.4.2 Organic Matter (OM) Analysis

Organic matter in sediment sample was determined by using the Loss-On-Ignition (LOI) method according to Nelson and Sommers (1982). An empty crucible was preheated in a muffled furnace (Carbolite) at 400 °C for two hours and the cooled crucible was weighed nearest to 0.1 mg. A sample with 3.0 g of air-dried sediment was ground by using mortar and sieved through a 355 µm sieve. The sieved sediment was transferred to the crucible and heated in an oven at 105 °C for 24 hours. The crucible was cooled in a desiccator over calcium chloride (CaCl₂) and the weight of the beaker plus the sample was recorded nearest to 0.1 mg. Then, the sample was ignited in a muffled furnace at 400 °C for 16 hours. The crucible was cooled in a desiccator over CaCl₂ and the weight of crucible plus ignited sample was recorded nearest to 0.1 mg.

The LOI content of the sample was calculated by using formula [17]:

$$LOI = \frac{W_{105} - W_{400}}{W_{105}} \times 100 \quad [17]$$

where,

LOI = organic matter content, %,

W_{105} = Weight of sediment after heating at 105 °C, and

W_{400} = Weight of sediment after ignition at 400 °C

4.2.4.3 Particle Size Distribution (PSA)

PSA of the sediment sample was conducted according to Gee and Bauder (1986). Organic matter has an aggregating effect hence, the removal of organic matter was necessary for PSA distribution.

4.2.4.3.1 Pre-treatment of Sediment

A sample with 20.0 g of air-dried sediment was weighed and transferred into a 600 mL beaker. Then, 25 mL of distilled water was added and the beaker was stirred to mix well. A volume of 5 mL of hydrogen peroxide (H_2O_2) was added to the sediment suspension. H_2O_2 was used to oxidize the organic matter inside the sediment. Then, the suspension was stirred and covered with a petri dish. When excessive frothing occurred, the beaker was cooled in cold water. Then, H_2O_2 was added when the reaction subsided. When the frothing has ceased, the suspension was heated to 90 °C in a water bath to evaporate the excess water present in the beaker. Next, H_2O_2 was added continuing during heating to further oxidize the organic matter present in the

sediment. The side of the beaker was rinsed occasionally with H_2O_2 . The peroxide and heat treatment was continued until the rate of reaction had slow down and the appearance of the bleached colour of the sediment sample. Then, the sample was heated for another hour to remove excess H_2O_2 . The suspension was transferred into a 1 L measuring cylinder. A 400 mL of distilled water and 10 mL of sodium hexametaphosphate (HMP) were added and shaken. Then, the cylinder was left to stand for overnight.

4.2.4.3.2 Separation of Sand Fractions

The suspension from the pre-treatment of sediment was sieved through a 53 μm sieve into a 1 L measuring cylinder. The washings on the sieve were collected. It was dried at 105 °C in an oven for overnight. The weight of the dried sand was weighed with weighing precision of 0.01 g. Then, the dried sand was transferred to the nest of sieves arranged from 2000 μm , 500 μm , 355 μm , 53 μm , and a pan. The sieves were shaken for three minutes. Then, each sand fraction was weighed and recorded.

4.2.4.3.3 Determination of Silt and Clay (< 2 μm)

The measuring cylinder which contained silt and clay suspension was placed in a water bath. A 10 mL of HMP solution was added into the cylinder and marked up to 1 L with distilled water. Then, the cylinder was covered with a watch glass. The suspension was left to stand for eight hours to equilibrate. After the equilibration, the suspension was stirred for 30 seconds by using an up-and-down motion. The time at completion of stirring and temperature of the water bath were recorded.

A 25 mL of sample was pipetted from the cylinder at 10 cm depth within 12 seconds after four minutes and one hour of interval respectively. Then, another 25 mL of sample was pipetted from the cylinder after seven hours of interval. The pipetted sample was placed into a 50 mL beaker. The pipet was rinsed with distilled water and the rinsed water was added into the beaker. The beaker was dried in an oven at 105 °C for overnight and cooled in a desiccator. Then, the beaker was weighed and the weight was recorded. The sample that was pipetted after four minutes indicated silt and clay fraction and seven hours indicated clay fraction.

The weights of the sand, silt and clay fractions in one litre were calculated by using formula [18]-[21]:

$$W_t = W_{sand} + W_{silt} + W_{clay} \quad [18]$$

$$\%_{sand} = \frac{W_{sand}}{W_t} \times 100 \% \quad [19]$$

$$\%_{silt} = \frac{W_{silt}}{W_t} \times 100 \% \quad [20]$$

$$\%_{clay} = \frac{W_{clay}}{W_t} \times 100 \% \quad [21]$$

The concentrations of the sand, silt and clay fractions in one litre were calculated by using formula [22]-[24]:

$$Conc_{sand} = W_{sand} \times \frac{1000}{25} \quad [22]$$

$$Conc_{silt} = W_{silt} \times \frac{1000}{25} \quad [23]$$

$$Conc_{clay} = W_{clay} \times \frac{1000}{25} \quad [24]$$

where,

W_t = Total weight of sediment, g,

W_{sand} = Weight of sand, g,

W_{silt} = Weight of silt, g,

W_{clay} = Weight of clay, g,

$\%_{sand}$ = Percentage of sand, %,

$\%_{silt}$ = Percentage of silt, %,

$\%_{clay}$ = Percentage of clay, %,

$Conc_{sand}$ = Concentration of sand (g/L) in sediment,

$Conc_{silt}$ = Concentration of silt (g/L) in sediment, and

$Conc_{clay}$ = Concentration of clay (g/L) in sediment

4.2.4.4 Total Organic Carbon (TOC) Analysis

Total organic carbon in the sediment was determined by using Walkley-Black method according to Nelson and Sommers (1982). The sediment was ground by using mortar and sieved through a 0.5 mm sieve. A 2 g sample of sediment was transferred into a 500 mL wide-mouth Erlenmeyer flask. Then, 10 mL of 0.167 M potassium dichromate ($K_2Cr_2O_7$) was added and the flask was swirled gently to disperse the sediment in the solution. Then, 20 mL of concentrated H_2SO_4 was added into the suspension. The flask was swirled until the sediment and reagents mixed well. Then, it was swirled vigorously for one minute. The flask was left to stand on an insulated sheet for about 30 minutes. Then, 200 mL of distilled water was added to the flask. The suspension was filtered by using a vacuum pump. Five drops of 0.025 M of o-phenanthroline-ferrous complex was added. The solution was titrated with 0.5 M of ferrous sulphate heptahydrate ($FeSO_4 \cdot 7H_2O$) solution. The solution changed from a greenish cast to dark green as the end point approached. $FeSO_4 \cdot 7H_2O$ solution was added drop by drop until a sharp colour changed from blue to red. A blank was analysed in the same manner but without the sediment to standardize the $K_2Cr_2O_7$ solution.

The percentage of TOC was calculated by using formula [25]:

$$TOC = \frac{(Blank-sample)(MFe^{2+})(0.003)(100)}{Weight} \times f \quad [25]$$

where,

TOC = Total organic carbon, %,

Weight = Weight of the sample taken, g, and

f = correction factor, 1.30

The concentration of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ was calculated by using formula [26]:

$$\text{FeSO}_4 \cdot 7\text{H}_2\text{O} = \frac{6 \times \text{mole of } \text{K}_2\text{Cr}_2\text{O}_7 \times \text{vol. } \text{K}_2\text{Cr}_2\text{O}_7}{\text{Vol. } \text{FeSO}_4} \quad [26]$$

where,

$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ = Ferrous sulphate heptahydrate, M, and

$\text{K}_2\text{Cr}_2\text{O}_7$ = Potassium dichromate, M

4.2.4.5 Total Kjeldahl Nitrogen (TKN) Analysis

Total Kjeldahl Nitrogen in the sediment was determined by using regular Kjeldahl method to detect the concentration according to Bremner (1996).

4.2.4.5.1 Digestion Process

A sample of 0.3 g of air-dried sediment was weighed and 1.1 g of potassium sulphate (K_2SO_4) catalyst mixture was added. Then, 3.0 ml of concentrated H_2SO_4 was added to the sample and the sample was transferred to a micro-Kjeldahl digestion flask. The flask was put in a heating digester (VELP SCIENTIFICA, DKL Heating Digester). Next, the sample was heated at 200 °C approximately two hours until the frothing had ceased and the temperature was increased to 220 °C until the sample was bleached. The flask was heated gently for another five hours.

4.2.4.5.2 Distillation Process

After the completion of digestion, the flask was allowed to cool to room temperature. Then, 20 mL of ammonia-free water was added slowly to the flask and shaken. A total volume of 10 mL of ammonia-free water was added to rinse the side of the flask. The suspension was filtered through the filtration set with a vacuum pump. Next, 20 mL of 10 M NaOH was added to the filtrate. The solution was transferred to the semi-automatic distillation unit (VELP SCIENTIFICA, UDK139). The timer was set for two and half minutes. Then, the distillate was measured and collected in a 250 mL Erlenmeyer flask which contained 5 mL of H_3BO_3 solution. The collection tube was placed into the H_3BO_3 solution to prevent the loss of ammonia gas.

4.2.4.5.3 Nessler's Method

The sediment sample was adjusted to pH 7 by using 1 N of NaOH and topped up to 100 mL with ammonia free water. Sample with a volume of 25 mL was placed into a culture tube and three drops of mineral stabilizer, three drops of polyvinyl alcohol dispersing agent and 1 mL of Nessler's reagent were added. The tube was inverted to mix completely. The absorbance was determined by using UV-VIS spectrophotometer (JASCO, V630) at 425 nm.

4.2.4.5.4 Calibration Steps

Firstly, anhydrous ammonium chloride (NH_4Cl) was dried in an oven at 105 °C for an hour and cooled in a desiccator. Then, 3.819 g of NH_4Cl was weighed. Stock NH_4Cl solution was prepared by dissolving the dried anhydrous NH_4Cl in distilled water and diluted to 1 L in a standard flask (1.0 mL= 1.00 mg N).

Secondly, intermediate NH_4Cl was prepared by diluting 25.0 mL of the stock solution to 1 L (1.0 mL = 0.025 mg N). Then, different concentrations of N were prepared by using the volume of 0.0, 5.0, 10.0, 15.0, 20.0, 25.0, and 30.0 mL. The different volumes were diluted to 250 mL in a standard flask. Next, the standard solutions were treated the same manner as the sample. A reagent blank was carried out through all the steps of the procedure.

The total Kjeldahl nitrogen concentration of the sediment was calculated by using formula [27]:

$$TKN = \left(\frac{abs + 0.03518}{0.21677} \right) \times \frac{100}{1000} \times \frac{1}{0.0003} \quad [27]$$

where,

TKN = Total Kjeldahl Nitrogen, mg/kg

Abs = Absorbance

Weight = Weight of the sediment sample, 0.003 kg

4.2.4.6 Total Phosphorus (TP) Analysis

The total phosphorus concentration in the sediment was determined by using perchloric acid digestion followed by ascorbic acid method according to Kuo (1996).

4.2.4.6.1 Perchloric Acid (HClO₄) Digestion

A sample of 2.0 g of air-dried sediment was mixed with 30 mL of 70 % perchloric acid (HClO₄) in a Kjeldahl tube. The tube was covered to ensure the reflux of the HClO₄. The heating digester (VELP SCIENTIFICA, DKL Heating Digester) was preheated at 130 °C for 30 minutes. Then, the flask was put in the heating digester. The mixture was digested at 130 °C until the disappearance of the dark colour. This is due to the loss of organic matter. In other words, the mixture was digested until bleached colour. Then, the mixture was digested at 203 °C for another 20 minutes. Digestion was completed when white fumes of HClO₄ appeared. Then, 2 mL of HClO₄ was added to wash down any black particles sticking to the sides of the flask.

After the digestion, the mixture was cooled and diluted to 250 mL with distilled water and mixed well. Then, the solid materials in the mixture were allowed to settle. A 50 mL of aliquot in the flask was transferred into a 250 mL of Erlenmeyer flask. Five drops of 0.25 % *p*-nitrophenol indicator was added to the solution. Then, 5 M NaOH was added dropwise until the colour changed from colourless to yellow. Then, the solution was marked up to 100 mL.

4.2.4.6.2 Ascorbic Acid Method

A 50 mL of the solution was transferred to an Erlenmeyer flask. An 8 mL of combined reagent was added to the solution. The solution was left for 10 minutes for the reaction time. Then, the absorbance was determined by using UV-VIS spectrophotometer (JASCO, V630) at 880 nm within 30 minutes.

4.2.4.6.3 Calibration Steps

Firstly, anhydrous potassium dihydrogen phosphate (KH_2PO_4) was dried in an oven at 105 °C for an hour and cooled in a desiccator. Then, 0.2195 g of KH_2PO_4 was weighed. Stock KH_2PO_4 solution was prepared by dissolving the dried KH_2PO_4 in distilled water and diluted to 1 L in a standard flask (1.0 mL = 50.0 µg P). Secondly, intermediate KH_2PO_4 solution was prepared by diluting 50 mL of the stock solution to 1 L (1.0 mL = 2.5 µg P). Then, different concentrations of P were prepared by using the volume of 0.0, 25.0, 50.0, 75.0, 100.0, 125.0, 150.0, 200.0, 225.0, and 250.0 mL. The different volumes were diluted to 250 mL in a standard flask. Next, the standard solutions were treated the same manner as the sample. A reagent blank was carried out through all the steps of the procedure.

The TP concentration was calculated by using formula [28]:

$$TP = \left(\frac{Abs + 0.00146}{0.00041} \right) \times \frac{1}{1000} \times \frac{250}{1000} \times \frac{1}{0.002} \quad [28]$$

where,

TP = Total phosphorus concentration, mg/kg, and

Abs = Absorbance

4.2.5 Statistical Analysis

Significant difference of each parameter among stations was analysed by using one-way ANOVA at the 5 % significance level. Tukey's test was used for pairwise comparisons among the stations. Relationship between the parameters were analysed by using bivariate correlation and two tailed Pearson. Principal components analysis (PCA) was used to show the grouping of parameters. Independent *t*-test was used to determine whether there is a statistically significant difference between the means in two unrelated groups, stations at the main river and the stations at tributaries. Paired *t*-test was used to determine whether there is a statistically significant difference between the means in two related groups, rainfall and no rainfall event of the stations at the main river and rainfall and no rainfall at the tributaries. All data analyses were conducted by using IBM SPSS Statistics 20. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario were used to classify the status of sediment characteristics of the upper Baram River.

4.3 Results and discussion

Results of the sediment characteristics in this study arranged in the direction from upstream to downstream area of the upper Baram River, Sarawak is shown in Figures 69 to 80. Appendix 27 shows the correlations between sediment parameters of the 30 stations.

4.3.1 Sediment pH

The mean sediment pH value of the stations from the upstream to the downstream at the upper Baram River ranged from 4.83 to 6.33 is shown in Figure 69. For the upstream area, station 1 (pH 6.25) at the main river, downstream of the longhouses of Lio Mato recorded the highest mean pH value and it is significantly higher than the other stations. Meanwhile, station 3 (pH 4.83) at the main river, downstream of the estuary of Temedan River recorded the lowest mean pH value and it is significantly lower than the other stations. For the midstream area, station 11 (pH 6.33) at the main river, downstream of the longhouses of Long Apu recorded the highest mean pH value and it is significantly higher than the other stations. Besides, station 12 at the main river, upstream of Long San's bridge recorded the lowest mean pH value and it is significantly lower than the other stations. The low pH value at station 12 is probably due to the discharge of untreated human and animal wastes such as manure and urine into the river. The organic wastes discharged such as urea was broken down into ammonia and ammonia undergoes oxidation to produce $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ and release hydrogen ions. Therefore, the release of hydrogen ions that reduced the pH values in the river was not favorable to aquatic organisms (Amneera *et al.*, 2013). For the downstream area, stations 24 (pH 5.03), 26 (pH 5.05) and 29 (pH 5.06) have significantly lower mean pH value than the other stations. This is because logging activities was carried out at station 24 and near to station 29 and longhouses are located at the upstream area of station 26. According to Haynes & Naidu (1998), low pH condition in sediments is unfavorable for nitrification. In addition, Figure 70 shows that the trend of the mean pH in the sediment was decreasing from upstream to downstream area at the upper Baram River, except for station 11. The pH of the sediment was negatively correlated with sand ($r = -0.533$, $p = 0.002$, $n = 30$) and TKN ($r = -0.501$, $p = 0.005$, $n = 30$) as presented in Appendix 26.

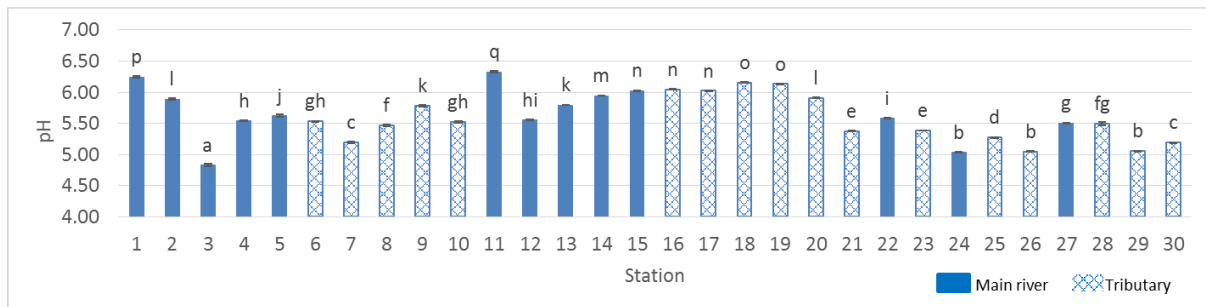


Figure 69: Mean sediment pH value at different stations from upstream (St 1-10) in Jul 2015, to midstream (St 11-20) in Sep 2015, and then downstream (St 21-30) in Jan 2015. Different letters show significant difference among the stations from upstream to downstream area of the upper Baram River ($p < 0.05$)

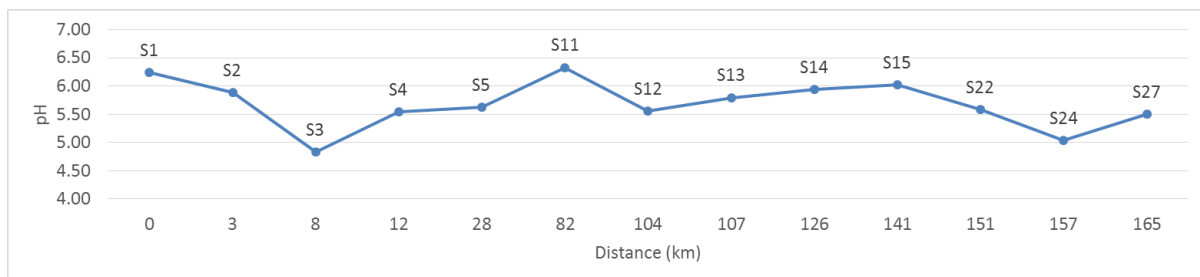


Figure 70: Mean sediment pH value at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in 2015

4.3.2 Particle Size Distribution (PSA)

Figure 71 presents the mean sand, silt and clay in percentage of the stations at the upper Baram River. Mean sand varied from 27.10 to 81.09 %. Meanwhile, mean silt ranged from 9.71 to 57.45 %, whereas, mean clay ranged from 0.94 to 21.34 %. For the sand, the highest mean sand recorded was at station 17 (81.09 %) at the Lasa River, a tributary, whereas, the second highest mean sand was located at station 18 (80.70 %) at the Akah River, a tributary (Figure 71 (a)). Meanwhile, station 28 (27.10 %) at the Nakan River, a tributary, recorded the lowest mean sand and it is showed significantly lower mean sand than the other stations. From Figure 72 (a), mean sand in the sediment of the stations at the main river shows a gradual decreasing trend from upstream to downstream area, except for station 27.

On the other hand, station 28 (57.45 %) at the Nakan River, a tributary, recorded the highest and it is showed significantly higher mean silt than the other stations (Figure 71 (b)). The lowest mean silt was located at station 20 (9.71 %) at the Patah River, a tributary. From Figure 72 (b), mean silt in the sediment of the stations at the main river shows a gradual decreasing trend from upstream to downstream area, except stations 22 and 24. For the clay, the highest mean clay was located at station 26 (21.34 %) at the Kesseh River, a tributary and it is significantly higher than other stations (Figure 71 (c)). Besides, the lowest mean clay was observed at station 9 (0.94 %) at the Sela'an River, a tributary. From Figure 72 (c), mean clay in the sediment of the stations at the main river shows an increasing trend from upstream to downstream area, except station 27.

Based on Appendix 29, the soil texture classification ternary diagram, only station 26 at Kesseh River, a tributary, was classified as sandy clay loam and station 28 at Nakan River, a tributary, as silt loam, whereas, stations 3, 5, 7, 8, 17, and 18 were classified as loamy sand. Besides, the other stations were classified as sandy loam. Clay content was positively correlated with silt ($r = 0.669$, $P = 0.000$, $n = 30$) as presented in Appendix 26.

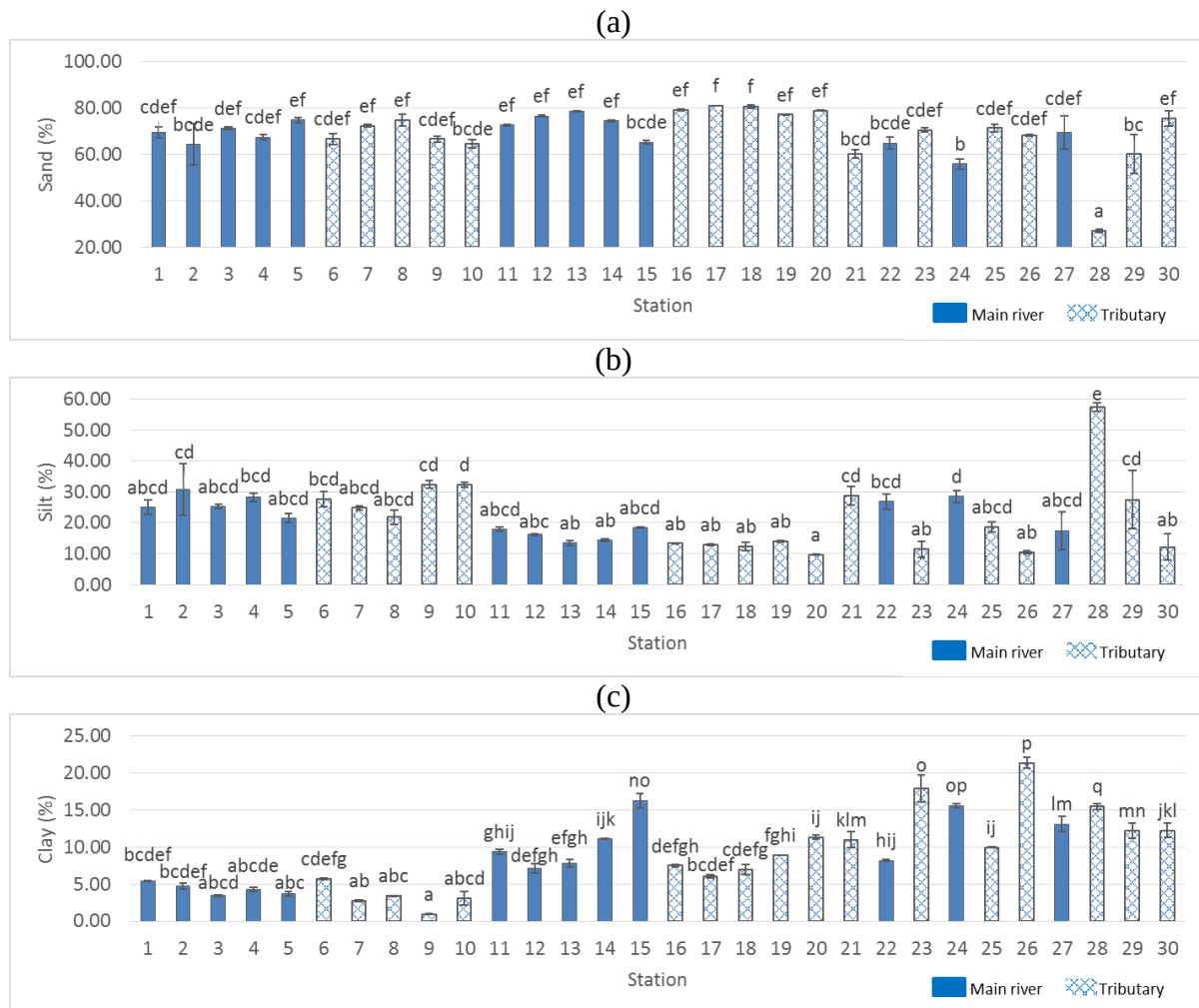


Figure 71: Mean (a) sand, (b) silt and (c) clay (%) at different stations from upstream (St 1-10) in Jul 2015 to midstream (St 11-20) in Sep 2015, then downstream (St 21-30) in Jan 2015. Different letters show significant difference among the stations from upstream to downstream area of the upper Baram River ($p < 0.05$)

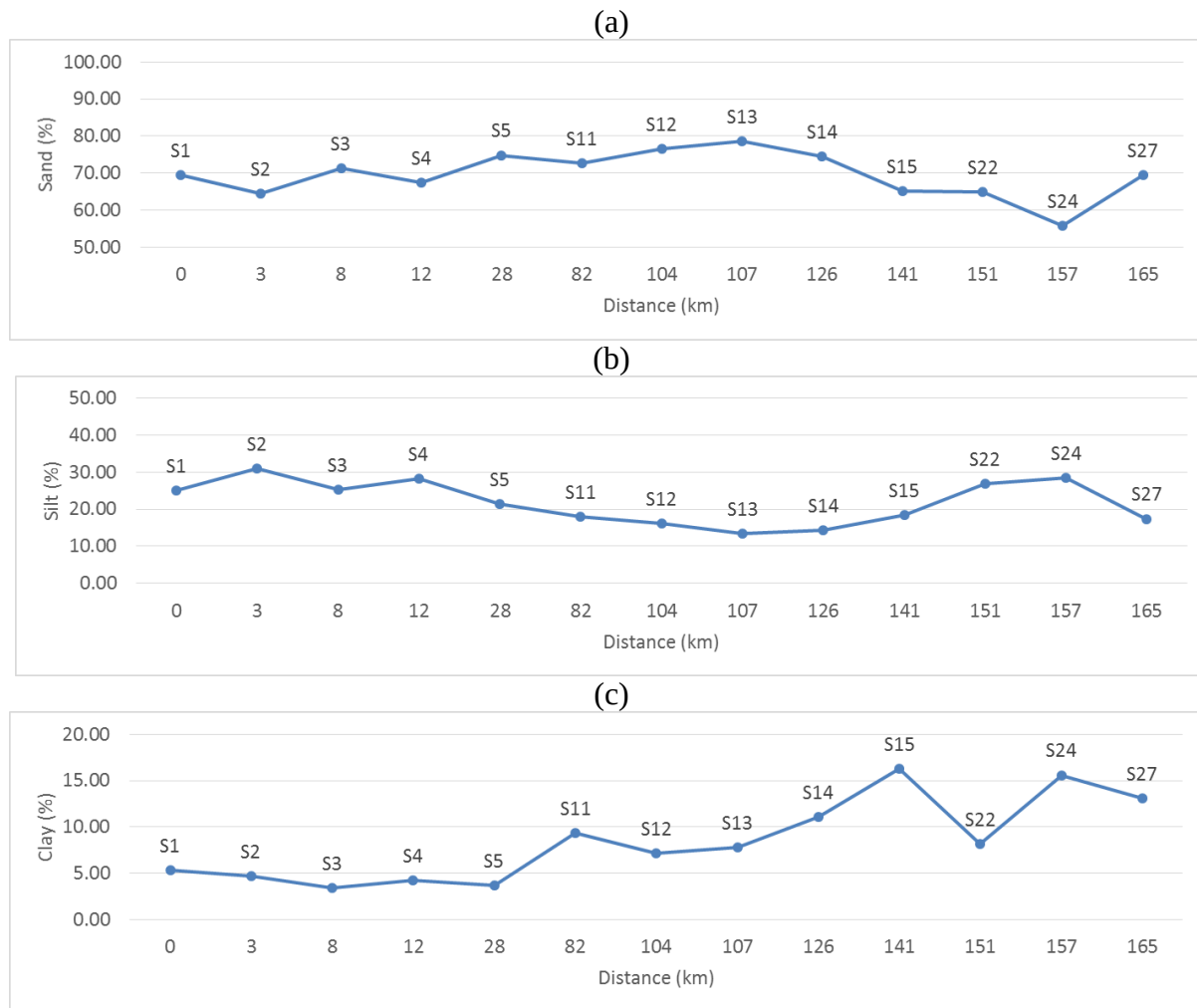


Figure 72: Mean (a) sand, (b) silt and (c) clay (%) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in 2015

4.3.3 Organic Matter (OM)

Figure 73 shows that the organic matter in sediment of the upper Baram River ranged from 0.30 to 4.80 %. For the upstream area, the highest mean organic matter recorded was at station 6 (2.69 %) at the Selungo River, a tributary, and the second highest mean organic matter was at station 8 (1.27 %) at the Sebatu River, a tributary. The lowest mean organic matter recorded were at station 3 (0.52 %) at the main river, downstream of the estuary of Temedan River followed by station 4 (0.47 %) at the main river, downstream of Long Semiyang (Figure 73). For the midstream area, the highest organic matter was at station 12 (1.69 %) at the main river, upstream of Long San's bridge. Station 17 (0.30 %) at the Lasa River, a tributary, showed the lowest organic matter and it was significantly lower than the other stations followed by station 18 (0.40 %) at the Akah River, a tributary (Figure 73). For the downstream area, the highest organic matter was located at station 28 (4.80 %) at the Nakan River, a tributary, and it showed significantly higher mean organic matter than the other stations. The second highest mean organic matter as located at station 23, followed by stations 25 and 26. The lowest organic matter was at station 30 (1.91 %) at the Kemenyeh River, a tributary, followed by station 21 (2.07 %) at the Kahah River, a tributary (Figure 73). The highest organic matter present in the sediment at station 6, 12, 23, 25, 26, and 28 were due to the discharge of human wastewater and animal wastes from both longhouses and logging activities and logging camp. The organic wastes discharged from the nearby logging and longhouses was broken down by bacteria into ammonia and oxidation of ammonia produced $\text{NO}_3\text{-N}$ which released hydrogen ions. The increase in amount of hydrogen ions is not favorable to aquatic organisms (Amneera *et al.*, 2013). The significantly higher mean organic matter present at the downstream area is probably due to the accumulation of the organic matter during heavy rainfall. This is because the organic matter was flushed down from the upstream area and accumulated at the downstream area.

The decaying roots, litter and crop residues from logging sites results increased returns of organic matter to the sediment (Lewandowski, 2017). According to Haynes & Naidu (1998), an increase in the production of plant biomass results in an increase of organic matter in the form of decaying crop residues. Based on Figure 74, the trend of the organic matter in the sediment at the upper Baram River is increasing from upstream to downstream area. The organic matter of the sediment was positively correlated with clay ($r = 0.834$, $P = 0.000$, $n = 30$) and silt ($r = 0.477$, $P = 0.008$, $n = 30$), whereas, organic matter was negatively correlated with pH ($r = -0.469$, $P = 0.009$, $n = 30$) as presented in Appendix 26.

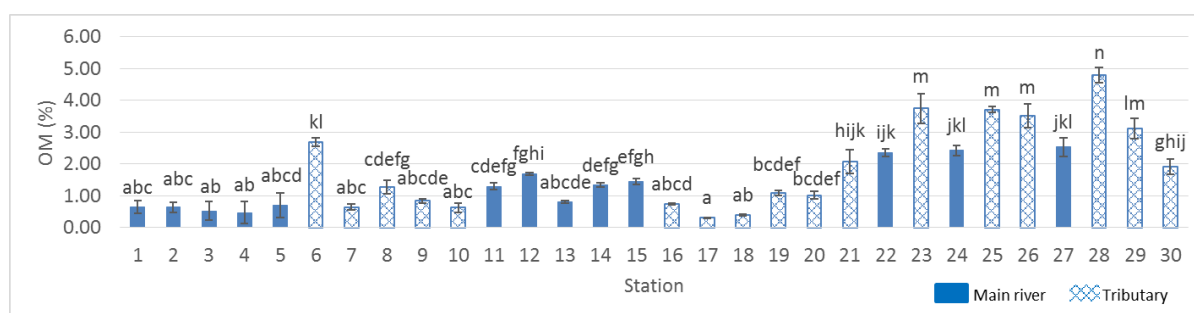


Figure 73: Mean organic matter (%) at different stations from upstream (St 1-10) in July, 2015, to midstream (St 11-20) in Sep, 2015, and then downstream (St 21-30) in Jan, 2015. Different letters show significant difference among the stations from upstream to downstream area of the upper Baram River ($p < 0.05$)

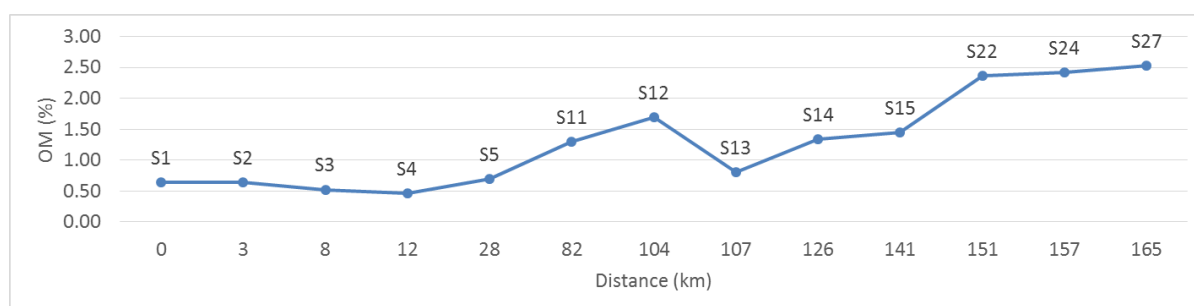


Figure 74: Mean organic matter (%) at different stations at the main river showing the trend from upstream to downstream of the upper Baram River, Sarawak in 2015

4.3.4 Total Organic Carbon (TOC)

The mean TOC of the stations at the upper Baram River is in the range of 0.15 to 1.38 % (Figure 75). For the upstream area, the highest mean TOC was located at station 6 (0.71 %), at the Selungo River, a tributary. The lowest and second lowest were located at station 4 (0.15 %) at the main river, downstream of longhouses of Long Semiyang and station 7 (0.17 %) at the Temedan River, a tributary respectively, and they were significantly lower in mean TOC than the other stations (Figure 75). For the midstream area, the lowest mean TOC was at station 18 (0.19 %) at the Akah River, a tributary, followed by station 17 (0.24 %) at the Lasa River, a tributary, and they were significantly lower in mean TOC than the other stations (Figure 75). For the midstream area, stations 11 (1.24 %), 12 (1.37 %), 14 (1.22 %), and 15 (1.19 %) recorded significantly higher mean TOC than the other stations. This is because stations 11, 12, 14, and 15 are near to longhouses. Therefore, the discharge of the household and human wastes resulted in the accumulation of organic carbon in the sediment. Manures and urea that entered the river results in an increase of nutrients thus an increase in organic carbon in sediment. Meanwhile, Davide *et al.* (2003), also supported that high levels of organic carbon mainly comes from anthropogenic inputs which are influenced by human activities. For the downstream area, station 23 (1.38 %) at the Piping River, a tributary, and station 25 (1.38 %) at the Jertang River, a tributary, recorded significantly higher mean TOC than the other stations. The lowest mean TOC was located at station 22 (0.77 %) at the main river, downstream of the estuary of Hit River (Figure 75). The high mean TOC at stations 23 and 25 were due to the fertilizers runoff from oil palm farm and human waste from nearby logging camp. Nasnolkar *et al.* (1996) also stated that high mean TOC observed in the sediment was due to the influx of land runoff which contained significant amount of organic matter.

Based on Figure 76, the trend of the mean TOC in the sediment at the upper Baram River was increasing from upstream to downstream area. The TOC of the sediment was positively correlated with organic matter ($r = 0.751$, $P = 0.000$, $n = 30$) and clay ($r = 0.640$, $P = 0.000$, $n = 30$) as presented in Appendix 26.

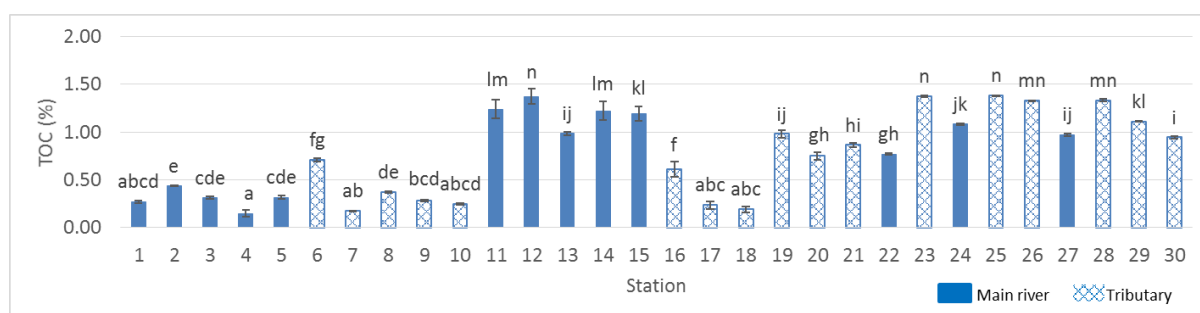


Figure 75: Mean TOC (%) at different stations from upstream (St 1-10) in Jul 2015, to midstream (St 11-20) in Sep 2015, and then downstream (St 21-30) in Jan 2015. Different letters show significant difference among the stations from upstream to downstream area of the upper Baram River ($p < 0.05$)

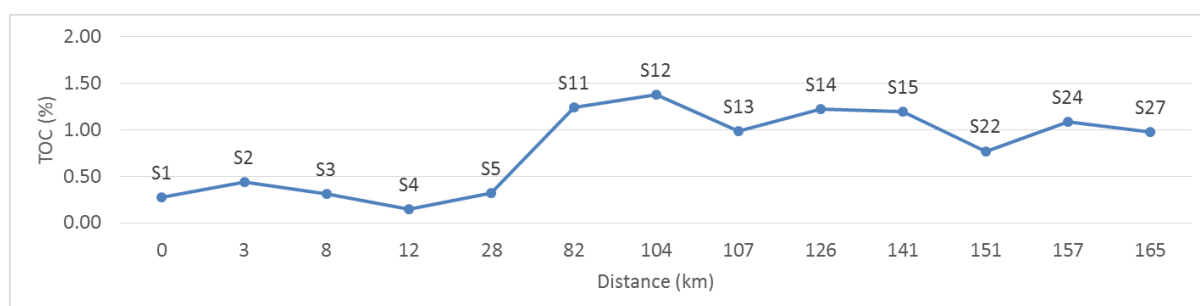


Figure 76: Mean TOC (%) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in 2015

4.3.5 Total Kjeldahl Nitrogen (TKN)

Figure 77 illustrates the mean TKN concentration of the stations at the upper Baram River. TKN concentration ranged from 185.1 to 1045.6 mg/kg (Figure 77). For the upstream area, the highest mean TKN concentration was at station 6 (916.2 mg/kg) at the Selungo River, a tributary, and it showed significantly higher in mean TKN than the other stations. The lowest mean TKN concentration was at station 3 (322.5 mg/kg) at the main river, downstream of the

estuary of Temedan River (Figure 77). For the midstream area, station 12 (789.4 mg/kg) at the main river, upstream of the Long San's bridge, it showed significantly higher in mean TKN than the other stations. Station 17 (185.8 mg/kg) at the Lasa River, a tributary, and station 18 (185.1 mg/kg) at the Akah River, a tributary recorded the lowest and the second lowest mean TKN concentration. Stations 17 and 18 were significantly lower in mean TKN than the other stations. The high mean TKN concentration recorded at the stations was most probably due to the runoff from nearby logging camp and longhouses. This is because discharge from sewage works and logging activities increased nutrients in the river through surface runoff. Boyes & Elliott (2006) also supported that the discharged from sewage works were affecting the levels of nutrients in the river. This is because the inputs from sewage treatment works was almost 33 % of the inputs of nutrient loadings at the Humber Estuary, England (Boyes & Elliott, 2006). For the downstream area, station 26 (1045.6 mg/kg) at the Kesseh River, a tributary, recorded the highest mean TKN concentration, followed by station 24 (937.9 mg/kg) at the main river, downstream of the estuary of Tanan River (Figure 77). Stations 24 and 26 were significantly higher in mean TKN concentration than the other stations. This is probably due to the runoff from agricultural land, human and animal waste from the upstream area. Ismail & Ibrahim (2015), also reported that nutrients entering the river through the disposal of the manure and animal husbandry as well as several wastewater treatment plants. In addition, the flow at station 26 ($35.1 \text{ m}^3/\text{s}$) was slow and so, nutrients are easily trapped and accumulated in the sediment. Trimmer *et al.* (1998) also reported that freshwater flushing time had a great impact on the nitrogen loads in the sediment. Based on Figure 78, the mean TKN at the upper Baram River was generally in an increasing trend from upstream to downstream area.

The TKN concentration in the sediment was negatively correlated with pH ($r = -0.501$, $P = 0.005$, $n = 30$), but positively correlated with organic matter ($r = 0.815$, $P = 0.000$, $n = 30$), clay ($r = 0.619$, $P = 0.000$, $n = 30$) and TOC ($r = 0.674$, $P = 0.000$, $n = 30$) as presented in Appendix 26.

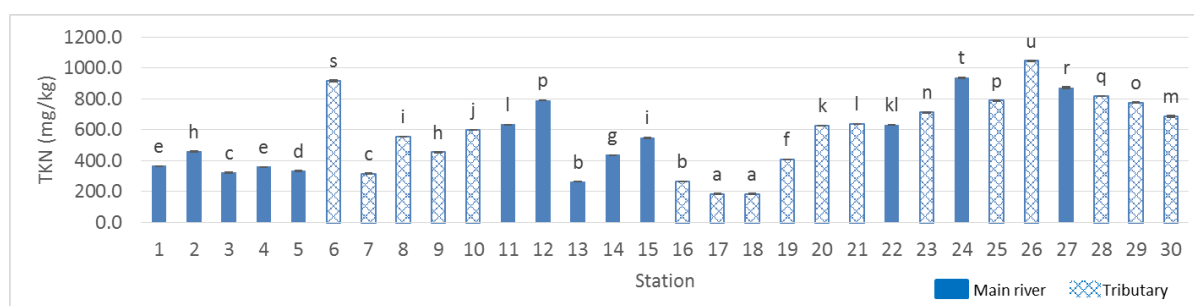


Figure 77: Mean TKN (mg/kg) at different stations from upstream (St 1-10) in Jul 2015, to midstream (St 11-20) in Sep 2015, and then downstream (St 21-30) in Jan 2015. Different letters show significant difference among the stations from upstream to downstream area of the upper Baram River ($p < 0.05$)

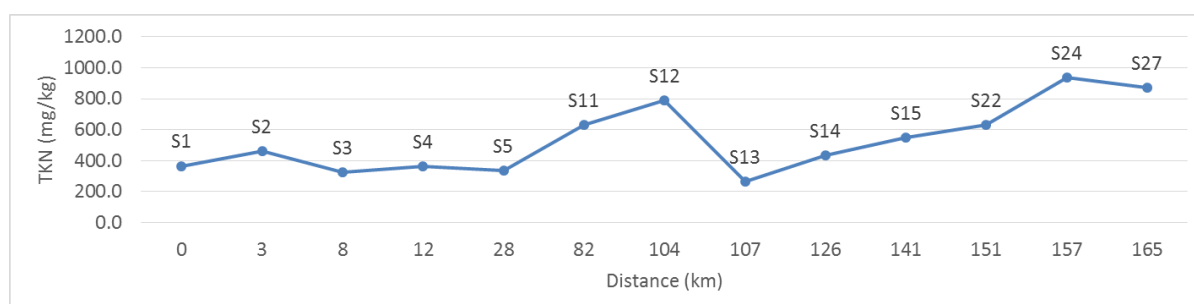


Figure 78: Mean TKN (mg/kg) at different stations at the main river showing the trend from upstream to downstream area of the upper Baram River, Sarawak in 2015

4.3.6 Total Phosphorus (TP)

Figure 79 shows that the mean TP concentration of the stations at the upper Baram River ranged from 15.0 to 536.8 mg/kg. For the upstream area, the mean TP concentration of stations 3 (18.7 mg/kg), 5 (22.9 mg/kg) and 10 (15.0 mg/kg) were significantly lower than the other stations. The low mean TP concentration of the stations was likely due to utilize of phosphate during photosynthesis activity thus, decreasing the TP concentration in the river. Nasnolkar *et al.* (1996)

also said that the intense photosynthetic activity consume phosphate and decreases phosphate concentration in the river. Meanwhile, the highest mean TP concentration was located at station 7 (239.4 mg/kg). For the midstream area, the highest mean TP concentration was recorded at station 18 (312.3 mg/kg) at the Akah River, a tributary. The significantly higher mean TP concentration was recorded at station 7 and 18 due to nearby logging activities. Organic waste was flushed down during heavy precipitation. The lowest mean TP concentration was recorded at station 15 (205.0 mg/kg) at the main river, downstream of the longhouses of Long Na'ah (Figure 79). For the downstream area, significantly higher mean TP concentration was observed at station 28 (536.8 mg/kg) at the Nakan River, a tributary, followed by station 23 at Piping River. Significantly higher mean organic matter was also observed at stations 23 and 28 (Figure 79). This is likely due to the increase in point source inputs such as household wastewater thus increasing the organic matter in the river and it settled from the water column to the bottom sediment. The decomposition of organic matter increased the phosphorus concentration in the sediment. Nasnolkar *et al.* (1996) and Walling *et al.* (2003) also stated that an increase in sediment phosphate is due to the increase in point source inputs and the decay of organic matter settling from the top. Based on Figure 80, the trend of the mean TP concentration in the sediment is increasing from upstream to downstream area. The TP concentration of the sediment was positively correlated with clay ($r = 0.707$, $P = 0.000$, $n = 30$), organic matter ($r = 0.665$, $P = 0.000$, $n = 30$) and TOC ($r = 0.647$, $P = 0.000$, $n = 30$) as presented in Appendix 26.

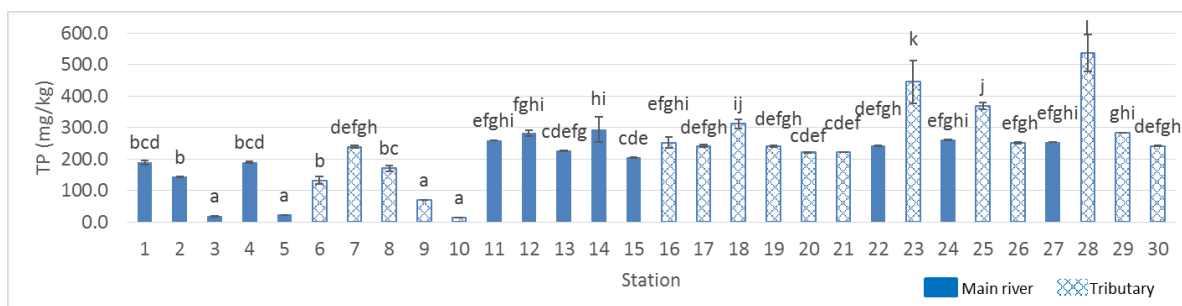


Figure 79: Mean TP (mg/kg) at different stations from upstream (St 1-10) in July, 2015 to midstream (St 11-20) in Sep, 2015, then downstream (St 21-30) in Jan, 2015. Different letters show significant difference among the stations from upstream to downstream area of the upper Baram River ($p < 0.05$)

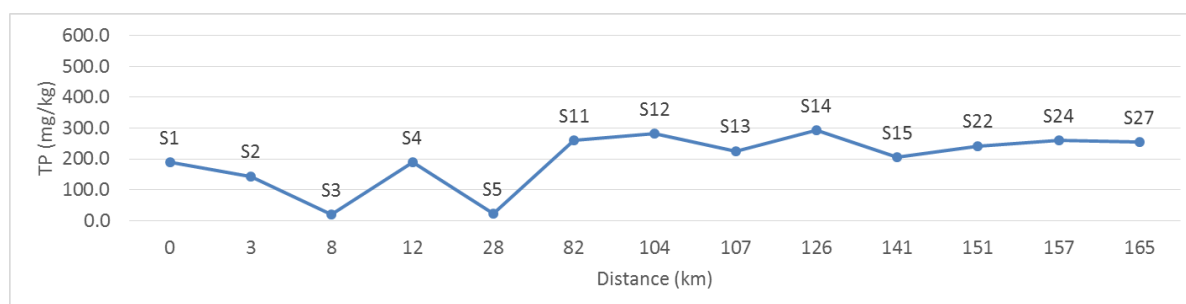


Figure 80: Mean TP (mg/kg) at different stations at the main river showing the trend from upstream to downstream area of the Baram River, Sarawak in 2015

Table 25 shows the criteria and guidelines for contaminated freshwater sediments. TP at all the stations showed the lowest effect level (600 mg/kg), 10 stations, 11, 12, 14, 15, 23, 24, 25, 26, 28, and 29, exceeded the lowest effect level for TOC (1 %) and 13 stations, 1, 2, 3, 4, 5, 7, 9, 13, 14, 16, 17, 18, and 19 exceeded the lowest effect level for TKN (550 mg/kg) according to the Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (Persaud & Jaagumagi, 1993)

Table 25: Criteria and guidelines for contaminated freshwater sediments (Persaud & Jaagumagi, 1993)

Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario						
Station	TP (mg/kg)		TOC (%)		TKN (mg/kg)	
1	189.5	LEL	0.27	LEL	365.2	LEL
2	143.9	LEL	0.44	LEL	460.0	LEL
3	18.7	LEL	0.31	LEL	322.5	LEL
4	190.2	LEL	0.15	LEL	360.3	LEL
5	22.9	LEL	0.32	LEL	333.7	LEL
6	132.1	LEL	0.71	LEL	916.2	> LEL
7	239.4	LEL	0.17	LEL	317.2	LEL
8	171.1	LEL	0.37	LEL	554.1	> LEL
9	71.0	LEL	0.28	LEL	455.0	LEL
10	15.0	LEL	0.25	LEL	599.5	> LEL
11	259.2	LEL	1.24	> LEL	632.5	> LEL
12	282.2	LEL	1.37	> LEL	789.4	> LEL
13	225.9	LEL	0.98	LEL	263.6	LEL
14	293.5	LEL	1.22	> LEL	435.6	LEL
15	205.0	LEL	1.19	> LEL	548.8	LEL
16	251.8	LEL	0.61	LEL	266.0	LEL
17	242.2	LEL	0.24	LEL	185.8	LEL
18	312.3	LEL	0.19	LEL	185.1	LEL
19	241.3	LEL	0.98	LEL	408.6	LEL
20	221.4	LEL	0.75	LEL	625.6	> LEL
21	222.2	LEL	0.86	LEL	637.6	> LEL
22	242.3	LEL	0.77	LEL	631.9	> LEL
23	445.6	LEL	1.38	>LEL	712.3	> LEL
24	261.2	LEL	1.08	> LEL	937.9	> LEL
25	369.9	LEL	1.38	> LEL	788.3	> LEL
26	251.4	LEL	1.33	> LEL	1045.6	> LEL
27	253.8	LEL	0.97	LEL	871.7	> LEL
28	536.8	LEL	1.33	> LEL	818.5	> LEL
29	283.4	LEL	1.11	> LEL	776.8	> LEL
30	241.5	LEL	0.94	LEL	685.9	> LEL
LEL	600		1		550	

4.4 Principal Component Analysis (PCA)

Component 1, which explains 49.1 % of the total variance has strong positive loadings on OM, clay, TKN, TOC, and moderately positive loading on TP (Table 26). This can be interpreted as anthropogenic sources pollution like logging, household and animal wastes with high levels of organic matter. Component 2 accounted for 23.9 % of the total variation where, pH was found to have a strong positive loadings and strong negative loadings on sand (Table 26). This grouping points to soil erosion due to anthropogenic activities such as logging activities.

Table 26: Loadings of the first two Varimax Rotated Factor Analysis of parameters

Parameter	Component	
	1	2
OM	0.969	
Clay	0.908	
TKN	0.846	
TOC	0.828	0.434
TP	0.631	0.454
Sand		-0.856
pH	-0.450	0.710
Silt	0.403	-0.500
Eigenvalues	3.928	1.911
% of Variance	49.10	23.9
Cumulative %	49.10	73.0

Appendix 27 shows the correlations of the stations between water quality parameters and sediment characteristics at the upper Baram River. Sediment pH is negatively correlated with mean $\text{NH}_3\text{-N}$ concentration. This indicates that the low pH present in sediment was due to the breakdown of organic waste to ammonia in the water by nitrogen bacteria. The increased amount of hydrogen ions in the water reduced the pH and affected the sediment pH. Organic matter and TOC is negatively correlated with the means of water $\text{NO}_3\text{-N}$ and Org-N concentrations. The decomposition of organic matter by bacteria produced organic residue and breakdown into ammonia and produce $\text{NO}_3\text{-N}$. Therefore, when organic matter decreased, the water $\text{NO}_3\text{-N}$ and Org-N increased due to nitrification process in the water.

4.5 Comparisons between the main river and tributaries

Table 27 shows the comparison of the stations between the main river and tributaries in sediment characteristics. Overall, this study found that the mean of sand of the main river was significantly higher in concentrations compared to tributaries. Meanwhile, means of clay and organic matter of the main river were significantly lower in concentrations compared to tributaries (Table 27).

Table 27: Comparison of sediment characteristics between the main river and tributaries from upstream to downstream area of the upper Baram River, Sarawak

Parameters	Main river	Mean	Tributaries	Mean	p-value
pH	4.8-6.3	5.7	5.1-6.2	5.6	$p>0.05$
Sand (%)	55.9-78.7	69.7	27.1-81.1	69.2	$p<0.05$
Silt (%)	13.5-30.9	21.9	9.7-57.5	21.6	$p>0.05$
Clay (%)	3.4-16.3	8.5	0.9-21.3	9.2	$p<0.05$
OM (%)	0.5-2.5	1.3	0.3-4.8	1.9	$p<0.05$
TOC (%)	0.2-1.4	0.8	0.2-1.4	0.8	$p>0.05$
TKN (mg/kg)	263.6-937.9	534.8	185.1-1045.6	587.0	$p>0.05$
TP (mg/kg)	18.7-293.5	199.1	15.0-536.8	250.0	$p>0.05$

Table 28 shows that the comparison of the impacts of different land uses on the parameters of sediment characteristics of the upper Baram River, Sarawak. Based on this study, logging activities were associated with low pH, high OM, high TOC, high TKN, and TP in the sediment. Moreover, nearby longhouses low pH, high TOC and TKN were observed in the river.

Table 28: Comparisons of the impacts of different land uses on the parameters of sediment characteristics of the upper Baram River, Sarawak

Activities	Logging	Longhouses	Logging and longhouses	No logging or longhouses
Low pH (<5.0)	24, 25	3		10
OM (>2.5 %)	6, 23, 25		28	26, 29
TOC (>1.2 %)	23, 25	11	13, 14, 15, 28	26, 29
TKN	6, 24, 25, 26, 30	27	28	12, 29
TP (> 300 mg/kg)	23, 25		18, 28	

CHAPTER 5

SUMMARY AND CONCLUSIONS

The present study found that the stations at the upper Baram River and its tributaries showed sign of pollution as indicated by high concentrations of turbidity, TSS, BOD, COD, and $\text{NH}_3\text{-N}$ in the river which exceeded Class II according to NWQS for Malaysia. From WQI, only DO, $\text{NH}_3\text{-N}$ and BOD_5 improved from the month Jan 2015 to Mar 2016. Furthermore, the means of DO and turbidity concentrations of the stations at the main river show an increasing trend from upstream to downstream area. Meanwhile, the means of temperature, specific conductance, pH, BOD_5 , TP, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, and Org-N concentrations of the stations at the main river showed a decreasing trend from upstream to downstream area at the upper Baram River. In addition, the means of sediment pH shows a decreasing trend from upstream to downstream areas at the upper Baram River. Meanwhile, the means of organic matter, TOC, TKN, and TP concentrations show an increasing trend from upstream to downstream area at the upper Baram River. Overall, this study found that the means of specific conductance, transparency, Chl-*a*, and $\text{NO}_2\text{-N}$ of the main river stations have significantly lower concentrations compared to tributaries. Besides, the means of DO, turbidity and TSS of the stations at the main river showed significantly higher concentrations compared to tributaries. Furthermore, this study also found that the means of sand of the main river was significantly higher in concentrations compared to tributaries. Meanwhile, means of clay and organic matter of the main river was significantly lower in concentrations compared to tributaries.

According to the DOE's water quality classification based on WQI, the stations from the upstream to downstream area at Baram River in 2015, only station 26 at Kesseh River, a tributary, and station 28 at Nakan River, a tributary, improved after rainfall events, which was classified as "clean" in Jan 2015, while the other stations were classified as "slightly polluted" in 2015. In Jan 2016, the other stations were classified as "slightly polluted", except for station 24 at the main river, Btg Tanan River indicated as "clean". In Mar 2016, stations 20, 23 and 26 indicated as "clean", while the other stations were classified as "slightly polluted". On the other hand, WQI of stations 22 at the main river, Btg Hit River and 25, Jertang River, a tributary became worsen after rainfall in Jan 15 compared to Jan and Mar 16. WQI of station 22 increased from 63.9 in Jan 2015 to 71.0 in Jan 2016 but dropped to 64.8 in Mar 2016. Meanwhile, WQI of station 25 changed from 64.8 in Jan 2015 to 77.9 in Jan 2016 and 75.3 in Mar 2016.

In general, the mean temperature and specific conductance of the stations at the downstream area was significantly lower in value in Jan 2015 (with rainfall) than in Jan 2016 (no rainfall) and Mar (no or low rainfall) 2016. Besides, the means of Chl-*a* and NH₃-N concentration in Jan 2015 was significantly higher than in Jan and Mar 2016. Furthermore, mean DO, turbidity and NO₂-N concentration of the stations at the downstream area showed significantly lower DO concentration in Jan 2016 than in Jan 2015 and Mar 2016. Besides, significantly higher mean BOD₅ and TP concentration was observed in Jan 2016 than Jan 2015 and Mar 2016. In addition, the means of pH and transparency of the stations at the downstream area was significantly lower value in Mar 2016 than in Jan 2015 and Jan 2016. Besides, the mean TSS and NO₃-N concentration of the stations was significantly higher in Mar 2016 than in Jan 2015 and Jan 2016. Moreover, there is no significant difference in means among the mean COD and Org-N concentration at different sampling dates.

PCA of the water grouping revealed that DO, pH, specific conductance, turbidity, TSS, NO₂-N were closely related to logging activities and discharge of domestic wastes and they were the most significant indicators of pollution of the water quality of the Upper Baram River. From this study, logging activities are associated with high temperature, low DO, high specific conductance, low pH, high turbidity, TSS, BOD₅, COD, and nutrients (TP, NO₂-N, NO₃-N, NH₃-N and Org-N concentrations) in the river. Moreover, stations nearby longhouses are associated with low pH, high turbidity, TSS, BOD₅, TP, NO₃-N and Org-N in the river. Stations 20, Patah River, 22, Btg Hit River and 24, Btg Tanan River and stations 6, Selungo River, and 7, Temendan River with logging activities were observed to have significantly higher TP, NO₂-N and Org-N concentrations. In addition, stations 27, Long Kesseh showed significantly lower pH, high turbidity, and TSS. Stations 14 and 15 with both logging activities and longhouses were observed to have significantly higher turbidity, TSS and COD in the river. PCA of the sediment grouping revealed that pH, OM, TOC, TP and TKN are closely related to logging and longhouses. Station 25, Jertang River with logging activities only showed significantly lower pH, high OM, TOC, TKN, and TP concentrations in the sediment. Meanwhile, station 28, Nakan River with both logging and longhouses was observed to have significantly higher OM, TOC, TKN, and TP concentrations in the sediment.

This study found that loading of all the pollutants (TSS, BOD₅, COD, TP, NO₂-N, NO₃-N, NH₃-N, and Org-N) at the main river stations showed a gradual increasing trend from upstream to downstream area in the year 2015. A total of 26,547,196 kg/day of TSS, 570,960 kg/day of BOD₅, 23,589,707 kg/day of COD, 40,141 kg/day TP, 329 kg/day of NO₂-N, 3,839 kg/day of NO₃-N, 54,725 kg/day of NH₃-N and 272,524 kg/day of Org-N were loaded from station 27 to the downstream of Baram River in the year 2015. Furthermore, loading of the pollutants in Jan

2016 were observed lower than the loading in Jan 2015, while, loading of pollutants in Mar 2016 were observed higher than in Jan 2016. Moreover, the loading of the pollutants at the tributaries (stations 20, 23, 25, 26, and 28) showed a decreasing trend from Jan 2015 to Jan 2016 and increasing from Jan 2016 to Mar 2016.

This study shows that Baram River was potentially polluted by logging activities and waste from longhouses. Therefore, proper management of land use that reduces pollution needs to be introduced.

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APPENDICES

Appendix 1: Mean values of temperature, specific conductance, pH, turbidity and transparency of the stations from upstream to downstream in the year 2015

Station	Temperature (°C)	DO (mg/L)	Specific conductance (μS/cm)	pH	Turbidity (NTU)	Transparency (m)
1	26.31±0.00	6.69±0.01	50.0±0.0	7.18±0.01	92.3±0.3	0.05±0.01
2	25.68±0.00	6.72±0.01	25.4±0.2	7.03±0.01	107.3±0.7	0.05±0.01
3	25.70±0.00	6.67±0.01	40.1±0.0	6.94±0.05	121.2±1.3	0.05±0.01
4	25.28±0.01	6.67±0.00	39.1±0.0	7.05±0.00	199.0±1.3	0.05±0.01
5	25.64±0.01	6.56±0.01	37.6±0.0	7.02±0.00	198.9±1.7	0.05±0.01
6	25.48±0.00	6.41±0.01	38.0±0.0	6.89±0.01	74.8±0.6	0.52±0.03
7	24.71±0.01	6.76±0.01	29.5±0.0	6.95±0.00	205.9±0.8	0.05±0.01
8	25.45±0.00	6.72±0.01	32.9±0.0	7.05±0.01	85.1±0.6	0.43±0.01
9	24.33±0.00	6.75±0.01	30.5±0.0	6.83±0.01	66.7±0.2	0.53±0.06
10	24.03±0.01	6.94±0.00	25.0±0.2	6.77±0.00	80.2±0.5	0.42±0.01
11	26.37±0.00	6.56±0.02	32.7±0.0	7.06±0.01	159.2±0.8	0.05±0.01
12	26.67±0.01	6.59±0.01	31.4±0.1	7.30±0.01	326.7±11.2	0.05±0.01
13	26.23±0.00	6.64±0.00	30.6±0.0	7.23±0.00	180.1±1.0	0.05±0.01
14	25.77±0.00	6.70±0.00	28.1±0.0	7.17±0.01	259.7±1.8	0.05±0.01
15	25.77±0.00	6.63±0.00	28.3±0.0	7.25±0.01	292.2±1.4	0.05±0.01
16	31.41±0.00	6.18±0.00	73.9±0.0	7.65±0.00	18.5±0.1	0.19±0.01
17	30.34±0.01	6.54±0.01	66.9±0.0	7.76±0.01	56.0±1.5	0.05±0.01
18	29.27±0.01	6.51±0.01	38.8±0.0	7.39±0.00	39.2±0.2	0.24±0.01
19	25.52±0.00	6.96±0.00	40.4±0.0	7.50±0.00	16.7±0.2	0.36±0.01
20	28.22±0.01	6.43±0.00	51.1±0.0	7.77±0.01	468.8±45.4	0.05±0.01
21	24.97±0.06	6.49±0.01	50.3±0.3	7.58±0.01	9.8±0.7	1.05±0.01
22	23.77±0.06	6.90±0.01	22.4±0.1	6.79±0.01	454.7±33.0	0.06±0.01
23	24.07±0.06	6.97±0.01	48.3±0.1	7.22±0.01	42.5±0.5	1.05±0.01
24	24.07±0.06	7.59±0.01	8.5±0.0	7.50±0.01	288.3±6.1	0.08±0.01
25	25.07±0.06	6.34±0.01	47.2±0.3	7.45±0.01	131.7±4.7	0.15±0.01
26	25.47±0.06	6.53±0.01	24.2±0.2	7.08±0.01	18.6±2.6	0.51±0.01
27	24.27±0.06	7.32±0.01	41.0±0.5	6.80±0.01	290.7±15.9	0.08±0.01
28	27.33±0.06	6.50±0.01	54.0±0.1	7.32±0.01	9.5±0.2	1.03±0.06
29	24.67±0.06	6.61±0.01	3.5±0.0	7.20±0.01	281.3±6.1	0.09±0.01
30	24.87±0.06	5.91±0.01	76.3±0.2	7.47±0.01	35.7±0.1	0.26±0.01

Appendix 2: Mean concentrations of TSS, Chl-*a*, BOD, COD, and TP of the stations from upstream to downstream in the year 2015

Station	TSS (mg/L)	Chl- <i>a</i> (mg/m ³)	BOD (mg/L)	COD (mg/L)	TP (µg/L)
1	86±5	1.6±0.1	8.34±0.24	79±4	1600.0±2.9
2	109±4	1.9±0.1	4.56±0.24	46±8	1035.3±37.5
3	110±7	1.9±0.2	6.15±0.24	51±4	768.8±88.1
4	160±13	0.9±0.1	4.08±0.24	26±9	2198.0±134.4
5	118±1	5.1±0.5	5.50±0.24	33±4	748.7±134.1
6	33±6	1.0±0.1	5.62±0.24	43±9	1357.8±68.9
7	153±5	5.8±0.4	5.05±0.24	41±4	1290.9±140.4
8	92±10	5.2±1.3	6.60±0.24	94±4	173.9±19.5
9	47±3	24.6±1.4	6.63±0.24	43±9	1225.1±129.0
10	54±3	17.9±0.3	6.78±0.24	36±4	293.5±14.6
11	172±9	6.5±0.2	3.30±0.16	110±4	727.8±0.7
12	222±11	5.5±0.2	5.83±0.16	182±4	750.1±0.8
13	161±19	7.3±0.1	5.08±0.16	143±4	243.9±0.8
14	268±18	4.2±0.2	5.18±0.16	138±8	116.0±0.9
15	318±22	6.9±0.5	4.37±0.33	113±4	151.0±1.0
16	13±2	3.6±0.3	4.77±0.16	136±4	195.5±3.5
17	14±4	1.2±0.1	2.72±0.16	102±9	99.1±2.2
18	37±4	11.1±1.3	2.52±0.16	102±9	213.1±0.6
19	25±2	0.4±0.1	2.56±0.16	84±8	47.2±0.1
20	320±19	8.3±0.2	2.54±0.16	87±9	59.7±0.6
21	6±2	0.9±0.0	3.65±0.04	72±8	157.1±6.0
22	246±45	1.3±0.1	3.63±0.03	69±9	486.0±0.9
23	40±9	0.3±0.0	3.23±0.05	85±8	188.4±0.3
24	267±20	1.1±0.3	2.86±0.05	32±9	19.6±1.9
25	97±1	0.2±0.0	3.81±0.04	256±21	10.7±3.5
26	7±1	1.7±0.0	1.83±0.05	21±9	41.6±0.1
27	232±13	13.1±1.9	3.09±0.05	21±5	170.3±18.2
28	6±1	11.9±0.8	2.81±0.04	45±9	114.7±1.5
29	212±21	23.3±0.7	3.40±0.02	91±24	33.3±0.7
30	21±1	0.3±0.0	4.19±0.04	165±5	26.2±0.0

Appendix 3: Mean concentrations of NO₂-N, NO₃-N, NH₃-N, and Org-N of the stations from upstream to downstream in the year 2015

Station	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	Org-N (mg/L)
1	0.007±0.001	0.03±0.01	0.81±0.00	1.75±0.00
2	0.013±0.002	0.03±0.00	0.72±0.00	2.15±0.00
3	0.014±0.004	0.03±0.00	0.60±0.00	1.45±0.01
4	0.012±0.002	0.07±0.01	0.70±0.00	1.78±0.01
5	0.008±0.001	0.07±0.01	0.86±0.00	1.64±0.00
6	0.025±0.003	0.02±0.01	0.81±0.01	2.11±0.01
7	0.038±0.002	0.08±0.03	0.64±0.00	2.74±0.01
8	0.009±0.001	0.03±0.01	0.77±0.00	2.31±0.01
9	0.007±0.000	0.04±0.01	0.72±0.00	1.19±0.04
10	0.016±0.004	0.09±0.01	0.70±0.00	1.02±0.00
11	0.001±0.001	0.01±0.00	0.17±0.00	0.99±0.01
12	0.000±0.001	0.02±0.01	0.12±0.01	0.63±0.02
13	0.002±0.000	0.02±0.01	0.33±0.00	1.66±0.01
14	0.001±0.001	0.03±0.01	0.25±0.01	1.34±0.05
15	0.010±0.001	0.03±0.01	0.12±0.00	1.58±0.03
16	0.007±0.001	0.02±0.01	0.20±0.01	0.69±0.01
17	0.003±0.001	0.02±0.01	0.12±0.01	0.46±0.02
18	0.011±0.001	0.02±0.01	0.19±0.00	1.36±0.02
19	0.007±0.001	0.03±0.01	0.16±0.01	0.77±0.01
20	0.055±0.001	0.03±0.01	0.15±0.00	0.83±0.02
21	0.005±0.000	0.01±0.01	1.57±0.07	0.25±0.04
22	0.007±0.001	0.02±0.01	1.49±0.20	0.32±0.01
23	0.006±0.001	0.03±0.01	0.32±0.01	1.93±0.13
24	0.008±0.000	0.02±0.01	1.01±0.03	0.82±0.02
25	0.009±0.001	0.02±0.01	0.91±0.02	0.07±0.01
26	0.004±0.001	0.02±0.01	0.32±0.04	0.15±0.00
27	0.005±0.001	0.02±0.01	0.53±0.01	0.11±0.01
28	0.003±0.001	0.01±0.01	0.49±0.03	0.11±0.02
29	0.008±0.002	0.01±0.01	0.23±0.01	0.25±0.01
30	0.002±0.001	0.01±0.01	0.85±0.06	0.67±0.04

Appendix 4: Mean values of temperature, specific conductance, pH, turbidity and transparency of the stations at the downstream area in Jan and Mar 2016

Station	Temperature (°C)	DO (mg/L)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Transparency (m)
Jan 2016						
15	27.62±0.01	6.26±0.00	37.8±0.0	7.08±0.01	70.6±0.4	0.20±0.01
20	27.61±0.01	6.20±0.00	53.6±0.0	7.39±0.01	25.3±0.2	0.43±0.01
22	28.29±0.01	6.14±0.00	40.7±0.0	7.42±0.01	86.6±0.3	0.18±0.01
23	25.70±0.01	6.46±0.00	48.1±0.0	7.50±0.01	34.6±0.0	0.30±0.01
24	27.86±0.00	6.13±0.00	41.4±0.0	7.38±0.00	88.8±0.0	0.14±0.01
25	26.33±0.01	6.32±0.00	45.3±0.0	7.27±0.01	36.7±0.0	0.15±0.01
26	26.46±0.00	6.15±0.00	61.3±0.0	7.12±0.01	3.1±0.0	1.10±0.10
27	28.13±0.00	6.07±0.00	41.9±0.0	7.27±0.01	26.7±0.1	0.36±0.01
28	27.61±0.00	6.02±0.00	80.8±0.0	7.22±0.01	17.2±0.2	0.88±0.01
31	28.23±0.00	6.05±0.00	42.3±0.0	7.15±0.00	31.1±0.0	0.33±0.01
Mar 2016						
15	28.23±0.01	6.78±0.00	35.9±0.0	6.25±0.01	1091.5±0.0	0.05±0.01
20	29.07±0.01	7.52±0.00	63.3±0.0	6.83±0.00	82.5±0.0	0.10±0.01
22	29.03±0.01	6.78±0.00	40.8±0.0	6.76±0.00	632.7±2.1	0.04±0.00
23	25.83±0.00	8.06±0.00	51.9±0.0	6.87±0.01	6.0±0.1	0.30±0.01
24	29.11±0.00	6.69±0.00	41.4±0.0	6.74±0.00	656.1±0.0	0.05±0.01
25	27.91±0.01	7.62±0.00	44.8±0.0	6.60±0.01	98.2±0.1	0.11±0.01
26	27.18±0.01	7.69±0.00	44.9±0.0	6.57±0.00	43.3±0.0	0.11±0.01
27	29.73±0.00	7.32±0.00	48.0±0.0	6.79±0.01	120.5±0.0	0.08±0.01
28	29.27±0.01	7.45±0.00	79.6±0.0	6.76±0.00	13.4±0.0	0.07±0.01
31	29.14±0.01	7.35±0.00	44.7±0.0	6.41±0.00	364.1±0.1	0.04±0.01

Appendix 5: Mean concentrations of TSS, Chl-*a*, BOD, COD, and TP of the stations at the downstream area in Jan and Mar 2016

Station	TSS (mg/L)	Chl- <i>a</i> (mg/m ³)	BOD (mg/L)	COD (mg/L)	TP (µg/L)
Jan 2016					
15	44±3	1.61±0.25	6.03±0.06	61.3±4.6	252.4±7.0
20	45±1	0.33±0.00	6.32±0.07	69.3±4.6	296.4±6.2
22	84±4	0.50±0.02	5.93±0.09	69.3±4.6	65.7±0.3
23	36±1	0.42±0.02	6.24±0.04	48.0±8.0	2087.4±18.2
24	53±4	0.40±0.01	3.98±0.06	16.0±8.0	138.1±3.9
25	27±1	0.16±0.00	3.82±0.04	37.3±9.2	62.8±0.2
26	5±1	0.75±0.04	6.34±0.04	64.0±8.0	486.0±18.2
27	21±1	0.32±0.01	7.06±0.06	64.0±8.0	213.0±0.8
28	8±0	0.39±0.01	7.04±0.02	85.3±4.6	1851.2±10.0
31	24±1	0.26±0.01	7.57±0.04	101.3±4.6	209.7±2.7
Mar 2016					
15	1363±28	2.49±0.08	5.80±0.22	88.0±9.2	97.2±1.2
20	42±6	2.50±0.28	3.32±0.59	56.0±4.6	705.0±19.0
22	919±17	1.84±0.51	6.63±0.08	74.7±4.6	750.6±18.3
23	31±6	0.76±0.03	4.34±0.22	40.0±8.0	880.7±15.4
24	789±7	2.25±0.05	5.41±0.39	74.7±4.6	227.0±6.1
25	49±2	2.29±0.06	4.54±0.15	90.7±8.0	130.1±2.0
26	57±3	0.97±0.09	4.49±0.08	58.7±4.6	161.7±1.2
27	133±5	5.38±0.10	4.15±0.34	32.0±8.0	252.9±0.4
28	44±2	2.97±0.06	4.59±0.08	42.7±4.6	178.4±2.3
31	145±6	1.93±0.30	2.59±0.08	58.0±4.6	546.6±29.2

Appendix 6: Mean concentrations of NO₂-N, NO₃-N, NH₃-N, and Org-N of the stations at the downstream area in Jan and Mar 2016

Station	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	Org-N (mg/L)
Jan 2016				
15	0.001±0.001	0.02±0.01	0.27±0.00	0.51±0.00
20	0.001±0.001	0.01±0.01	0.21±0.00	0.43±0.01
22	0.002±0.000	0.01±0.01	0.31±0.00	0.63±0.00
23	0.002±0.001	0.05±0.01	0.18±0.00	0.41±0.00
24	0.002±0.000	0.03±0.01	0.18±0.00	0.45±0.01
25	0.001±0.001	0.01±0.01	0.66±0.00	0.64±0.01
26	0.001±0.001	0.01±0.00	0.38±0.00	0.50±0.00
27	0.000±0.000	0.00±0.00	0.55±0.00	0.55±0.02
28	0.000±0.000	0.01±0.00	0.22±0.00	0.40±0.01
31	0.000±0.000	0.00±0.00	0.67±0.00	0.86±0.01
Mar 2016				
15	0.007±0.001	0.00±0.00	0.25±0.00	0.06±0.00
20	0.005±0.001	0.01±0.00	0.20±0.00	0.08±0.01
22	0.006±0.001	0.00±0.00	0.27±0.00	0.12±0.01
23	0.001±0.001	0.04±0.01	0.27±0.00	0.20±0.00
24	0.004±0.001	0.01±0.00	0.24±0.00	0.26±0.00
25	0.004±0.001	0.08±0.01	0.25±0.00	0.28±0.00
26	0.003±0.001	0.06±0.01	0.25±0.01	0.22±0.00
27	0.015±0.001	0.02±0.01	0.26±0.00	0.35±0.01
28	0.004±0.001	0.01±0.00	0.25±0.00	0.34±0.00
31	0.010±0.001	0.01±0.00	0.23±0.00	0.38±0.01

Appendix 7: Calibration curve for PO₄-P concentration

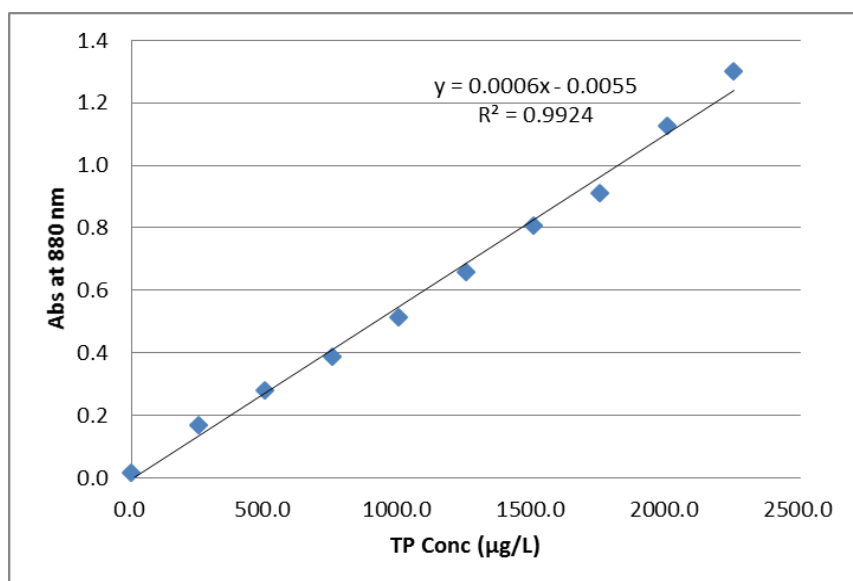
PO ₄ -P (µg/L)	Abs at 880 nm
0.0	0.0
250.0	0.2
500.0	0.3
750.0	0.4
1000.0	0.5
1250.0	0.7
1500.0	0.8
1750.0	0.9
2000.0	1.1
2250.0	1.3

Calibration Equation:

$$Y = 0.0006X - 0.0055$$

To calculate sample concentration, x:

$$X = (Y + 0.00549) / 0.00055$$



Appendix 8: Calibration curve for NH₃-N concentration

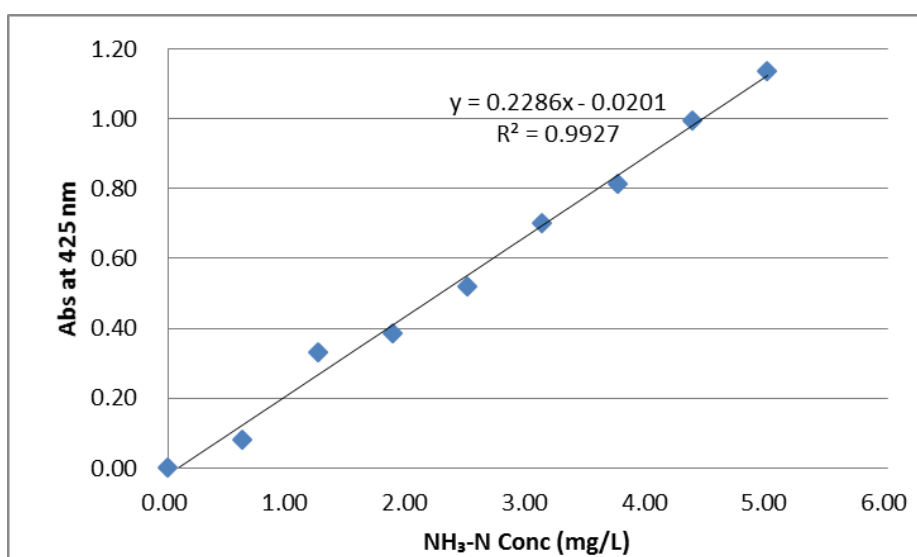
NH ₃ -N (mg/L)	Abs at 425 nm
0.00	0.00
0.63	0.08
1.25	0.33
1.88	0.38
2.50	0.52
3.13	0.70
3.75	0.81
4.38	0.99
5.00	1.14

Calibration Equation:

$$Y = 0.2286X - 0.0201$$

To calculate sample concentration, x:

$$X = (Y + 0.0201) / 0.2286$$



Appendix 9: Calibration curve for Org-N concentration

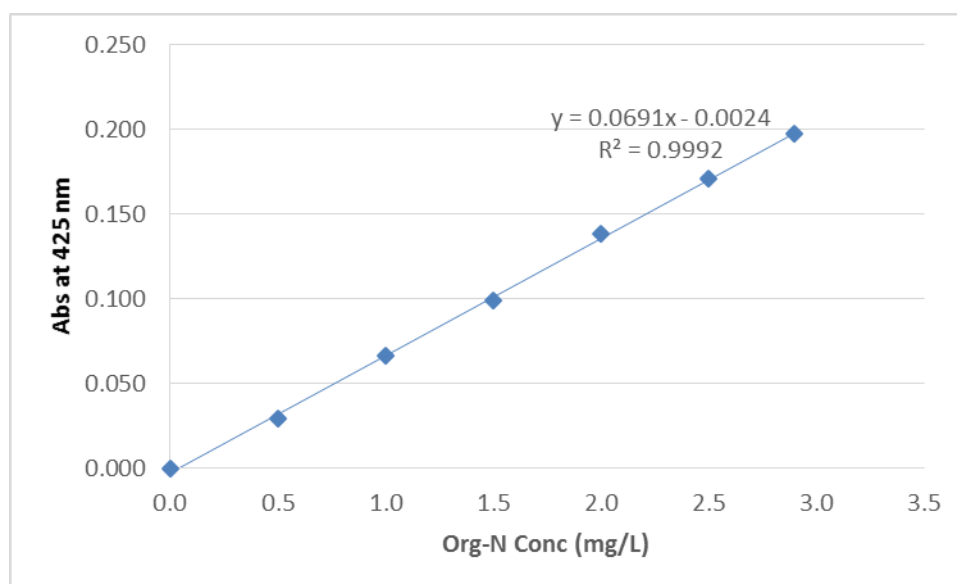
Org-N (mg/L)	Abs at 425 nm
0.0	0.000
0.5	0.029
1.0	0.067
1.5	0.099
2.0	0.138
2.5	0.171
2.9	0.198

Calibration Equation:

$$y=0.0691x-0.0024$$

To calculate sample concentration, x:

$$x=(y+0.0024)/0.0691$$



Appendix 10: Guidelines of National Water Quality Standards (NWQS) for Malaysia

Parameter	Unit	Class				
		I	IIA/IIB	III [#]	IV	V
Al	mg/l	Natural Levels or Absent	-	(0.06)	0.5	Levels above IV
As	mg/l		0.05	0.4 (0.05)	0.1	
Ba	mg/l		1	-	-	
Cd	mg/l		0.01	0.01* (0.001)	0.01	
Cr (IV)	mg/l		0.05	1.4 (0.05)	0.1	
Cr (III)	mg/l		-	2.5	-	
Cu	mg/l		0.02	-	-	
Hardness	mg/l		250	-	-	
Ca	mg/l		-	-	-	
Mg	mg/l		-	-	-	
Na	mg/l		-	-	3 SAR	
K	mg/l		-	-	-	
Fe	mg/l		1	1	1 (Leaf) 5 (Others)	
Pd	mg/l		0.05	0.02* (0.01)	5	
Mn	mg/l		0.1	0.1	0.2	
Hg	mg/l		0.001	0.004 (0.0001)	0.002	
Ni	mg/l		0.05	0.9*	0.2	
Se	mg/l		0.01	0.25 (0.04)	0.02	
Ag	mg/l		0.05	0.0002	-	
Sn	mg/l		-	0.004	-	
U	mg/l		-	-	-	
Zn	mg/l		5	0.4*	2	
B	mg/l		1	(3.4)	0.8	
Cl	mg/l		200	-	80	
Cl ₂	mg/l		-	(0.02)	-	
CN	mg/l		0.02	0.06 (0.02)	-	
F	mg/l		1.5	10	1	
NO ₂	mg/l		0.4	0.4 (0.03)	1	
NO ₃	mg/l		7	-	5	
P	mg/l		0.2	0.1	-	
Silica	mg/l		50	-	-	
SO ₄	mg/l		250	-	-	
S	mg/l		0.05	(0.001)	-	
CO ₂	mg/l		-	-	-	
Gross- α	Bg/l		0.01	-	-	
Gross- β	Bg/l		1	-	-	
Ra-226	Bg/l		< 0.1	-	-	
Sr-90	Bg/l		< 1	-	-	
CCE	µg/l		500	-	-	
MBAS/BAS	µg/l		500	5000 (200)	-	
O&G (Mineral)	µg/l		40 ; N	N	-	
O&G (Emulsified Edible)	µg/l		7000 ; N	N	-	
PCB	µg/l		0.1	6 (0.05)	-	
Phenol	µg/l		10	-	-	
Aldrin/Dieldrin	µg/l		0.02	0.2 (0.01)	-	
BHC	µg/l		2	9 (0.1)	-	
Chlordane	µg/l		0.08	2 (0.02)	-	
t-DDT	µg/l		0.1	(1)	-	
Endosulfan	µg/l		10	-	-	
Heptachlor/Epoxide	µg/l		0.05	0.9 (0.06)	-	
Lindane	µg/l		2	3 (0.4)	-	
2,4-D	µg/l		70	450	-	
2,4,5-T	µg/l		10	160	-	
2,4,5-TP	µg/l		4	850	-	
Paraquat	µg/l		10	1800	-	

Notes

* = At hardness 50 mg/l CaCO₃

= Maximum (un-bracketed) and 24-hour average (bracketed) concentrations

N = Free from visible film sheen, discolouration and deposits

Appendix 11: Guidelines of National Water Quality Standards (NWQS) for Malaysia

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Ammoniacal-Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand ₅	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	µS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	%	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
Total Dissolved Solid	mg/l	500	1000	-	-	4000	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Coliform**	count/100 ml	10	100	400	5000 (20000) _a	5000 (20000) _a	-
Total Coliform	count/100 ml	100	5000	5000	50000	50000	> 50000

Notes

* = At hardness 50 mg/l CaCO₃

= Maximum (un-bracketed) and 24-hour average (bracketed) concentrations

N = Free from visible film sheen, discolouration and deposits

Appendix 12: Uses based on water classes

Class	Uses
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III – Common of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above.

Appendix 13: DOE Water Quality Classification based on Water Quality Index

Sub Index & Water Quality Index	Index Range		
	Clean	Slightly Polluted	Polluted
Biochemical Oxygen Demand (BOD)	91 - 100	80 - 90	0 - 79
Ammoniacal-Nitrogen (NH ₃ -N)	92 - 100	71 - 91	0 - 70
Suspended Solids (SS)	76 - 100	70 - 75	0 - 69
Water Quality Index (WQI)	81 - 100	60 - 80	0 - 59

Appendix 14: WQI Formula and Calculation

$$WQI = (0.22 \cdot SIDO) + (0.19 \cdot SIBOD) + (0.16 \cdot SICOD) + (0.15 \cdot SIAN) + (0.16 \cdot SISS) + (0.12 \cdot SIpH)$$

where,

SIDO	= SubIndex DO (% saturation)
SIBOD	= SubIndex BOD
SICOD	= SubIndex COD
SIAN	= SubIndex NH ₃ -N
SISS	= SubIndex SS
SIpH	= SubIndex pH

$$0 \leq WQI \leq 100$$

Best Fit Equations for the Estimation of Various SubIndex (SI) Values:

SubIndex for DO (In % saturation)

$SIDO = 0$	for $x \leq 8$
$SIDO = 100$	for $x \leq 92$
$SIDO = -0.395 + 0.030x^2 - 0.00020x^3$	for $8 < x < 92$

SubIndex for BOD

$SIDOD = 100.4 - 4.23x$	for $x \leq 5$
$SIDOD = 108 \cdot \exp(-0.055x) - 0.1x$	for $x > 5$

SubIndex for COD

$SICOD = -1.33x + 99.1$	for $x \leq 20$
$SICOD = 103 \cdot \exp(-0.0157x) - 0.04x$	for $x > 20$

SubIndex for NH₃-N

$SIAN = 100.5 - 105x$	for $x \leq 0.3$
$SIAN = 94 \cdot \exp(-0.573x) - 5 \cdot I x - 2 I$	for $0.3 < x < 4$
$SIAN = 0$	for $x \geq 4$

SubIndex for SS

$SISS = 97.5 \cdot \exp(-0.00676x) + 0.05x$	for $x \leq 100$
$SISS = 71 \cdot \exp(-0.0061x) + 0.015x$	for $100 < x < 1000$
$SISS = 0$	for $x \geq 1000$

SubIndex for pH

$SIpH = 17.02 - 17.2x + 5.02x^2$	for $x < 5.5$
$SIpH = -242 + 95.5x - 6.67x^2$	for $5.5 \leq x < 7$
$SIpH = -181 + 82.4x - 6.05x^2$	for $7 \leq x < 8.75$
$SIpH = 536 - 77.0x + 2.76x^2$	for $x \geq 8.75$

Note:

*means multiply with

Appendix 15:Criteria and guidelines for contaminated freshwater sediments (Batts & Cubbage, 1995)

	Guidelines for the Protection and Mgmt. of Aqu. Sed. Quality in Ontario (Persaud <i>et al.</i> , 1993)		
Parameters	TP (mg/kg)	TOC (%)	TKN (mg/kg)
No Effect Level (NEL)	-	-	-
Lowest Effect Level (LEL)	600	1	550
Severe Effect Level (SEL)	2000	10	4800

Appendix 16: Mean values of pH, sand, silt, clay, organic matter (OM), TOC, TKN, and TP of the stations from upstream to downstream in the year 2015

Station	pH H ₂ O	Sand (%)	Silt (%)	Clay (%)	OM (%)	TOC (%)	TKN (mg/kg)	TP (mg/kg)
1	6.25±0.01	69.6±2.3	25.1±2.4	5.4±0.1	0.64±0.20	0.27±0.01	365.2±1.1	189.5±7.3
2	5.89±0.01	64.4±8.8	30.9±8.4	4.7±0.4	0.64±0.17	0.44±0.01	460.0±2.4	143.9±2.0
3	4.83±0.02	71.4±0.6	25.2±0.7	3.4±0.1	0.52±0.28	0.31±0.02	322.5±0.7	18.7±1.7
4	5.54±0.01	67.5±1.0	28.2±1.3	4.3±0.2	0.47±0.35	0.15±0.04	360.3±0.5	190.2±3.0
5	5.62±0.02	74.9±1.2	21.5±1.5	3.7±0.3	0.70±0.38	0.32±0.02	333.7±0.5	22.9±0.1
6	5.53±0.01	66.7±2.4	27.6±2.5	5.7±0.1	2.69±0.13	0.71±0.02	916.2±3.2	132.1±12.4
7	5.20±0.02	72.4±0.6	24.8±0.7	2.7±0.1	0.64±0.10	0.17±0.01	317.2±2.2	239.4±3.7
8	5.47±0.02	74.8±2.4	21.8±2.4	3.4±0.1	1.27±0.21	0.37±0.01	554.1±0.7	171.1±9.0
9	5.78±0.02	66.6±1.3	32.4±1.2	0.9±0.1	0.83±0.07	0.28±0.01	455.0±1.1	71.0±0.5
10	5.52±0.02	64.6±1.8	32.3±0.9	3.1±0.9	0.62±0.14	0.25±0.01	599.5±0.6	15.0±0.1
11	6.33±0.01	72.7±0.3	17.9±0.6	9.4±0.3	1.30±0.11	1.24±0.10	632.5±0.7	259.2±0.7
12	5.55±0.01	76.6±0.3	16.2±0.3	7.2±0.6	1.69±0.04	1.37±0.08	789.4±0.8	282.2±9.3
13	5.80±0.01	78.7±0.3	13.5±0.8	7.8±0.5	0.80±0.04	0.98±0.02	263.6±0.1	225.9±0.8
14	5.95±0.01	74.5±0.4	14.4±0.4	11.1±0.1	1.34±0.06	1.22±0.10	435.5±1.7	293.5±40.1
15	6.03±0.01	65.2±0.8	18.5±0.2	16.3±1.0	1.45±0.10	1.19±0.08	548.7±2.5	205.0±1.4
16	6.05±0.01	79.2±0.4	13.3±0.2	7.5±0.2	0.74±0.02	0.61±0.08	266.0±0.9	251.8±17.2
17	6.02±0.01	81.1±0.1	12.9±0.2	6.0±0.3	0.30±0.02	0.24±0.04	185.8±2.0	242.2±4.3
18	6.16±0.01	80.7±0.7	12.3±1.3	7.0±0.7	0.40±0.03	0.19±0.03	185.1±2.0	312.3±15.1
19	6.13±0.01	77.2±0.3	13.9±0.3	8.9±0.0	1.08±0.08	0.98±0.04	408.6±0.3	241.3±2.5
20	5.91±0.01	79.0±0.1	9.7±0.2	11.3±0.3	1.02±0.12	0.75±0.04	625.6±0.8	221.4±2.1
21	5.38±0.01	60.2±1.9	28.8±3.0	11.0±1.1	2.07±0.38	0.86±0.02	637.6±1.9	222.2±1.2
22	5.58±0.01	65.0±2.6	26.9±2.4	8.2±0.1	2.36±0.11	0.77±0.01	631.9±1.0	242.3±0.9
23	5.39±0.01	70.6±0.8	11.5±2.6	17.9±1.8	3.75±0.47	1.38±0.01	712.3±1.9	445.6±68.6
24	5.03±0.01	55.9±2.2	28.5±1.9	15.6±0.3	2.42±0.15	1.08±0.01	937.9±2.6	261.2±0.3
25	5.27±0.01	71.4±1.6	18.7±1.7	9.9±0.1	3.71±0.08	1.38±0.01	788.3±0.8	369.9±10.9
26	5.05±0.01	68.2±0.2	10.4±0.5	21.3±0.7	3.51±0.37	1.33±0.00	1045.5±3.3	251.4±3.7
27	5.51±0.01	69.5±7.3	17.4±6.3	13.1±1.0	2.53±0.28	0.97±0.01	871.7±4.8	253.8±0.3
28	5.50±0.03	27.1±0.9	57.5±1.3	15.5±0.4	4.80±0.24	1.33±0.01	818.5±1.7	536.8±57.7
29	5.06±0.01	60.3±8.4	27.5±9.4	12.2±1.0	3.11±0.32	1.11±0.00	776.8±2.7	283.4±0.8
30	5.19±0.01	75.6±3.2	12.2±4.2	12.2±1.0	1.91±0.24	0.94±0.01	685.9±4.4	241.5±1.2

Appendix 17: Records of Daily Total Rainfall Amount (mm) from January to December 2015

Month /Date	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
1	120.4	0.0	9.2	0.0	11.6	5.8	0.0	3.6	0.0	0.0	12.0	1.4
2	2.8	19.8	0.0	4.8	5.2	T	0.0	0.0	0.0	0.0	2.6	54.8
3	8.0	18.4	0.0	T	8.6	0.0	0.0	34.4	24.4	0.2	4.8	2.8
4	1.0	2.0	3.0	6.8	0.2	0.0	T	45.8	2.2	0.2	0.0	1.0
5	8.8	0.0	2.8	9.0	0.0	T	0.0	14.6	0.6	0.0	0.0	64.4
6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	8.6	33.0	0.0	2.8	0.2
7	0.4	0.0	0.0	0.0	0.0	3.0	0.0	3.8	0.0	21.4	5.2	0.0
8	0.0	0.2	0.0	1.0	0.0	1.2	17.4	0.0	1.0	11.6	7.4	0.0
9	42.6	T	0.0	0.0	0.0	7.2	3.4	0.0	0.0	23.2	5.6	12.6
10	5.0	25.8	0.0	0.0	0.0	12.4	2.8	0.0	2.0	42.0	13.2	44.4
11	21.0	1.0	0.0	0.0	0.0	6.8	0.0	0.0	8.8	0.0	4.2	9.4
12	0.0	3.8	0.0	0.0	0.0	27.0	0.0	9.2	0.0	1.8	46.6	6.2
13	16.4	0.0	0.0	0.0	14.2	1.4	8.6	1.4	0.0	0.0	7.8	4.0
14	48.0	37.6	0.0	0.0	2.0	24.2	2.6	1.8	83.6	0.0	0.6	0.2
15	0.0	5.2	0.0	3.8	6.6	0.2	0.0	0.6	1.8	0.0	8.8	0.2
16	12.6	2.0	0.0	0.0	0.0	163.0	0.0	2.2	0.0	12.4	0.0	32.8
17	5.6	2.8	0.0	45.2	0.0	2.4	0.0	4.6	0.0	12.4	1.8	38.6
18	29.4	0.0	0.0	14.2	12.8	0.0	0.0	0.6	0.0	6.0	14.2	9.8
19	7.6	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	3.6	0.4
20	47.4	0.0	0.0	9.8	0.0	1.4	33.6	0.0	0.0	0.0	0.4	0.6
21	13.6	0.4	0.0	0.0	0.0	0.4	1.8	0.0	0.0	0.0	45.4	0.6
22	32.8	0.0	0.0	5.0	0.2	0.0	0.0	0.0	0.0	1.8	3.8	0.0
23	3.4	0.0	0.0	0.0	6.2	0.0	1.2	0.0	0.0	2.0	24.4	8.6
24	10.8	0.0	0.2	3.4	0.0	0.0	39.8	0.0	2.8	0.0	45.0	16.6
25	4.4	0.0	0.0	3.2	T	0.0	3.8	0.0	0.2	0.0	0.0	0.0
26	35.6	0.0	0.4	0.0	1.8	0.0	16.2	9.4	0.0	0.0	22.8	2.2
27	1.4	3.6	0.0	57.4	10.8	0.0	40.6	0.0	0.0	0.0	3.8	1.8
28	0.0	0.0	0.0	0.0	0.0	0.0	11.2	3.6	0.0	0.0	14.6	0.0
29	3.6		0.0	0.0	0.0	3.0	0.0	0.0	4.4	8.0	0.0	0.0
30	166.4		0.2	18.6	0.8	0.0	2.4	25.0	0.0	T	4.8	0.0
31	3.0		0.0		0.0		30.6	0.2		7.6		0.0
Total	652.8	122.6	15.8	182.2	81.4	259.4	216.0	169.4	164.8	150.6	306.2	313.6
No. Rain days	27	13	6	13	14	15	15	17	12	14	25	23

T: Amount < 0.2 mm

* Rainfall amount during sampling trip is indicated in bold.

Appendix 18: Records of Daily Total Rainfall Amount (mm) from January to July 2016

Month /Date	Jan	Feb	Mar	Apr	May	June	Jul
1	0.0	0.0	0.0	0.0	16.8	0.2	2.2
2	0.0	0.0	10.0	7.2	0.2	0.0	0.0
3	5.0	3.6	16.0	0.0	0.4	4.4	0.0
4	T	57.2	0.6	0.0	1.4	3.4	0.0
5	0.0	0.0	0.0	0.2	10.6	0.0	0.0
6	0.0	0.4	0.0	10.6	1.0	0.2	0.0
7	0.0	5.8	0.2	0.0	66.2	0.0	0.0
8	0.0	4.8	0.0	0.0	0.6	0.0	0.0
9	T	1.8	0.0	3.4	0.0	0.0	0.0
10	17.6	7.8	0.0	T	0.0	0.0	0.0
11	41.2	0.0	1.4	0.0	50.4	3.4	0.0
12	0.0	0.0	0.0	0.0	0.8	0.0	0.0
13	0.0	0.0	0.0	2.4	22.4	2.8	0.0
14	0.0	0.0	0.0	T	0.0	0.2	0.8
15	0.0	0.0	2.2	0.0	23.0	0.0	0.4
16	0.0	0.0	0.0	0.0	14.2	3.2	2.4
17	0.0	0.0	9.8	0.0	0.0	22.2	20.4
18	0.0	0.0	1.6	0.0	0.0	4.8	0.0
19	0.0	0.0	0.0	0.0	0.4	5.2	0.0
20	1.4	0.0	0.0	0.0	0.0	0.0	13.8
21	0.2	0.0	0.0	6.4	0.0	20.8	114.8
22	5.2	0.0	0.0	0.0	0.8	0.2	0.0
23	0.0	0.0	0.0	12.8	2.4	T	30.4
24	0.0	0.0	11.8	9.8	0.0	0.0	7.8
25	0.0	0.0	0.4	0.0	0.0	18.2	3.6
26	0.0	0.0	0.0	18.2	0.0	0.0	11.4
27	0.0	0.0	27.2	0.0	0.0	25.6	1.4
28	0.0	0.0	0.8	36.0	0.0	0.0	0.0
29	0.0	0.0	0.0	57.8	5.0	0.0	7.4
30	0.0		3.4	0.0	0.2	12.8	8.4
31	0.0		0.4		12.0		39.8
Total	70.6	81.4	85.8	164.8	228.8	127.6	265.0
No. Rain days	6	7	14	11	19	16	15
T: Amount < 0.2 mm							

* Rainfall amount during sampling trip is indicated in bold.

Appendix 19: Hydro-geometric data of the stations at the main river at the upper Baram River, Sarawak taken in the year 2015 and 2016

Station	Distance (km)	Mean Width (m)	Mean Depth (m)	Mean Velocity, (m/s)	Cross-sectional Area (m ²)	Flow (m ³ /s)
Jul-Sep-Jan 2015*						
1	0	44	1.2	1.60	54.6	126.3
2	2.6	62	1.6	1.10	101.8	164.9
3	8.3	76	0.8	1.77	70.6	154.9
4	12.2	84	1.5	0.76	161.2	150.6
5	28.1	54	1.4	1.72	82.1	183.5
11	82.4	114	2.4	0.55	295.2	258.0
12	104.1	149	1.6	1.13	206.4	285.1
13	106.7	122	2.0	0.58	272.8	232.0
14	125.5	130	3.2	1.48	438.5	745.5
15	140.6	108	2.5	1.01	285.9	476.4
22	151.4	120	1.8	1.09	254.3	382.0
24	157.2	120	14.1	1.07	1977.3	2711.8
27	164.6	137	5.2	1.73	843.9	1904.5
Jan 2016*						
15	140.6	92	2.1	0.59	238.6	199.6
22	151.4	92	3.1	0.22	302.7	130.4
24	157.2	105	4.2	0.21	540.1	177.2
27	164.6	101	2.3	0.24	300.4	111.5
31	171.9	121	3.7	0.31	434.5	152.7
Mar 2016*						
15	140.6	120	10.0	1.42	1699.3	3042.0
22	151.4	129	6.0	0.66	1030.6	1372.3
24	157.2	131	6.2	0.42	821.6	485.8
27	164.6	156	3.1	0.18	641.3	151.7
31	171.9	128	2.4	0.13	354.9	69.7

* Data in year 2015 taken during rainy season and data in Jan and Mar 2016 taken during dry season

Appendix 20: Hydro-geometric data of the stations at the tributaries at the upper Baram River, Sarawak taken in the year 2015 and 2016

Station	Width (m)	Mean Depth (m)	Mean Velocity, (m/s)	Area (m ²)	Flow (m ³ /s)	Inflow (%)
Jul-Sep-Jan 2015*						
6	32	0.7	0.73	25.3	35.1	4.4
7	38	0.9	0.23	44.2	27.1	3.4
8	23	0.3	1.26	7.7	136.5	16.9
9	34	1.2	1.76	52.5	182.6	22.6
10	42	1.8	1.30	104.1	64.9	8.0
16	31	0.2	0.11	8.3	1.6	0.2
17	30	0.2	0.07	7.4	104.5	13.0
18	62	4.0	0.25	336.1	129.2	16.0
19	23	0.7	0.28	18.1	39.5	4.9
20	67	1.4	0.18	119.9	33.1	4.1
21	28	2.1	0.06	70.6	4.8	0.6
23	26	2.5	0.08	78.4	7.1	0.9
25	20	4.0	0.06	90.4	5.5	0.7
26	38	2.8	0.06	123.5	8.3	1.0
28	45	5.2	0.07	275.8	20.0	2.5
29	16	2.3	0.07	44.8	3.2	0.4
30	22	2.5	0.06	63.8	3.7	0.5
Jan 2016*						
20	34	1.0	0.56	41.6	32.3	20.9
23	26	0.2	0.51	5.1	29.8	19.3
25	12	0.2	0.44	2.0	1.3	0.9
26	13	0.4	0.06	5.7	6.7	4.3
28	27	0.3	0.20	9.7	84.5	54.6
Mar 2016*						
20	70	2.7	0.18	207.7	46.5	9.9
23	10	1.7	0.06	16.2	218.0	46.2
25	24	0.9	1.08	26.1	43.3	9.2
26	15	0.4	0.82	6.6	112.7	23.9
28	45	0.6	0.20	31.4	51.3	10.9

* Data in year 2015 taken during rainy season and data in Jan and Mar 2016 taken during dry season

Appendix 21: NWQS for Malaysia of the means of DO, pH, Sp C, turbidity, TSS, TP, NO₂-N, NO₃-N, NH₃-N, BOD, and COD of the stations from the upstream to the downstream area at the upper Baram River in 2015

Station	DO	pH	Sp C	Turbidity	TSS	TP	NO ₂ -N	NO ₃ -N	NH ₃ -N	BOD	COD
Jul 2015											
1	II	I	I	>II	III	I	I	II	III	III	IV
2	II	I	I	>II	III	I	I	II	III	III	III
3	II	I	I	>II	III	I	I	II	III	III	IV
4	II	I	I	>II	IV	I	I	II	III	II	III
5	II	I	I	>II	III	I	I	II	III	III	III
6	II	I	I	>II	II	I	I	II	III	III	III
7	II	I	I	>II	IV	I	I	II	III	III	III
8	II	I	I	>II	III	II	I	II	III	III	IV
9	II	I	I	>II	II	I	I	II	III	III	III
10	II	I	I	>II	III	I	I	II	III	III	III
Sep 2015											
11	II	I	I	II	IV	I	I	II	II	II	V
12	II	I	I	>II	IV	I	I	II	II	III	V
13	II	I	I	>II	IV	II	I	II	III	III	V
14	II	I	I	>II	IV	II	I	II	II	III	V
15	II	I	I	>II	V	II	I	II	II	II	V
16	II	I	I	II	I	II	I	II	II	III	V
17	II	I	I	>II	I	I	I	II	II	II	V
18	II	I	I	II	II	II	I	II	II	II	V
19	II	I	I	II	II	II	I	II	II	II	IV
20	II	I	I	>II	V	II	I	II	II	II	IV
Jan 2015											
21	II	I	I	II	I	II	I	II	IV	II	IV
22	II	I	I	>II	IV	II	I	II	IV	II	IV
23	II	I	I	II	II	II	I	II	III	II	IV
24	I	I	I	>II	IV	II	I	II	IV	II	III
25	II	I	I	>II	III	II	I	II	IV	II	V
26	II	I	I	II	I	II	I	II	III	II	II
27	I	I	I	>II	IV	II	I	II	III	II	II
28	II	I	I	II	I	II	I	II	III	II	III
29	II	I	I	>II	IV	I	I	II	II	II	IV
30	II	I	I	II	I	I	I	II	III	II	V
Class II	5-7	6-9	1000	50	50	0.2	0.4	7	0.3	3	25

Appendix 22: NWQS for Malaysia of the means of DO, pH, SpC, turbidity, NH₃-N, BOD, COD, and TSS of the stations at the downstream area of the upper Baram River in 2016

Station	DO	pH	Sp C	Turbidity	TSS	TP	NO ₂ -N	NO ₃ -N	NH ₃ -N	BOD	COD
Jan 2016											
15	II	I	I	>II	II	I	I	II	II	III	IV
20	II	I	I	II	II	I	I	II	II	III	IV
22	II	I	I	>II	III	II	I	II	III	III	IV
23	II	I	I	II	II	I	I	II	II	III	III
24	II	I	I	>II	III	II	I	II	II	II	II
25	II	I	I	II	II	II	I	II	III	II	III
26	II	I	I	I	I	I	I	II	III	III	IV
27	II	I	I	II	I	I	I	II	III	III	IV
28	II	I	I	II	I	I	I	II	II	III	IV
31	II	I	I	II	I	I	I	II	III	III	V
Mar 2016											
15	II	II	I	>II	V	II	I	II	II	III	IV
20	I	I	I	>II	II	I	I	II	II	II	IV
22	II	I	I	>II	V	I	I	II	II	III	IV
23	I	I	I	II	II	I	I	II	II	II	III
24	II	I	I	>II	V	I	I	II	II	III	IV
25	I	I	I	>II	II	II	I	II	II	III	IV
26	I	I	I	II	III	II	I	II	II	III	IV
27	I	I	I	>II	III	I	I	II	II	II	III
28	I	I	I	II	II	II	I	II	II	III	III
31	I	II	I	>II	III	I	I	II	II	II	IV
Class II	5-7	6-9	1000	50	50	0.2	0.4	7	0.3	3	25

Appendix 23: Ratio of BOD to COD concentration of the stations from the upstream to downstream area at the upper Baram River, in 2015

	Station	Ratio BOD/COD
Upstream area, Jul, 2015	1	0.11
	2	0.10
	3	0.12
	4	0.16
	5	0.17
	6	0.13
	7	0.12
	8	0.07
	9	0.15
	10	0.19
Midstream area, Sep, 2015	11	0.03
	12	0.03
	13	0.04
	14	0.04
	15	0.04
	16	0.04
	17	0.03
	18	0.02
	19	0.03
	20	0.03
Downstream area, Jan, 2015	21	0.05
	22	0.05
	23	0.04
	24	0.09
	25	0.01
	26	0.09
	27	0.14
	28	0.06
	29	0.04
	30	0.03

Appendix 24: Ratio of BOD to COD concentrations of the stations at downstream area at the upper Baram River, in 2016

Station	Downstream area, Jan 2016	Downstream area, Mar, 2016
15	0.10	0.07
20	0.09	0.06
22	0.09	0.09
23	0.13	0.11
24	0.25	0.07
25	0.10	0.05
26	0.10	0.08
27	0.11	0.13
28	0.08	0.11
31	0.07	0.04

Appendix 25: Correlation of water quality parameters (N=50)

		Temp	Sp C	pH	DO	Tur	Trans	TSS	Chla	BOD ₅	COD	NO ₂ N	NO ₃ N	TAN	OrgN	TP
Temp	Pearson	1	.519**	-.001	-.075	.087	-.216	.148	-.235	.031	.069	-.086	-.359*	-.571**	-.358*	-.177
	Sig. (2-tailed)		.000	.992	.606	.548	.132	.304	.101	.829	.635	.552	.011	.000	.011	.219
Sp C	Pearson		1	.180	-.147	-.317*	.276	-.247	-.387**	.072	.128	-.150	-.217	-.205	-.289*	.079
	Sig. (2-tailed)			.212	.308	.025	.053	.084	.005	.619	.374	.300	.129	.153	.042	.588
pH	Pearson			1	-.551**	-.410**	.206	-.418**	-.108	-.179	.335*	.042	-.171	.021	.070	-.133
	Sig. (2-tailed)				.000	.003	.151	.003	.454	.215	.017	.774	.236	.885	.630	.357
DO	Pearson				1	.135	-.271	.102	.088	-.308*	-.301*	.049	.325*	-.069	-.123	-.032
	Sig. (2-tailed)					.350	.057	.483	.542	.029	.033	.733	.021	.633	.395	.828
Turbidity	Pearson					1	-.418**	.937**	.066	.015	.076	.231	-.150	-.058	-.143	-.089
	Sig. (2-tailed)						.003	.000	.650	.919	.598	.107	.298	.691	.323	.537
Trans	Pearson						1	-.354*	.000	.079	-.125	-.174	-.101	.209	-.024	.033
	Sig. (2-tailed)							.012	.998	.587	.386	.226	.487	.145	.868	.820
TSS	Pearson							1	.019	.101	.069	.103	-.217	-.135	-.158	-.087
	Sig. (2-tailed)								.898	.486	.633	.478	.131	.348	.272	.550
Chla	Pearson								1	-.058	-.066	.210	.190	-.049	.077	-.062
	Sig. (2-tailed)									.692	.650	.143	.187	.736	.594	.669
BOD ₅	Pearson									1	.030	-.172	.058	.086	.217	.392**
	Sig. (2-tailed)										.835	.233	.691	.551	.129	.005
COD	Pearson										1	-.124	-.238	-.071	-.035	-.250
	Sig. (2-tailed)											.392	.097	.626	.811	.080
NO ₂ N	Pearson											1	.334*	.088	.414**	.117
	Sig. (2-tailed)												.018	.543	.003	.418
NO ₃ N	Pearson												1	.093	.410**	.324*
	Sig. (2-tailed)													.519	.003	.022
NH ₃ N	Pearson													1	.218	.094
	Sig. (2-tailed)														.128	.518
OrgN	Pearson														1	.354*
	Sig. (2-tailed)															.012
TP	Pearson															1
	Sig. (2-tailed)															

Appendix 26: Correlations between sediment parameters of the 30 stations

		pH	Sand	Silt	Clay	OM	TOC	TKN	TP
pH	Pearson	1	-.533**	-.205	-.320	-.469**	-.153	-.501**	.014
	Sig. (2-tailed)		.002	.278	.084	.009	.418	.005	.942
	N	30	30	30	30	30	30	30	30
Sand	Pearson		1	.172	-.009	.122	-.395*	.088	-.155
	Sig. (2-tailed)			.364	.962	.521	.031	.645	.413
	N			30	30	30	30	30	30
Silt	Pearson			1	.669**	.477**	.101	.265	.333
	Sig. (2-tailed)				.000	.008	.597	.157	.072
	N				30	30	30	30	30
Clay	Pearson				1	.834**	.640**	.619**	.707**
	Sig. (2-tailed)					.000	.000	.000	.000
	N					30	30	30	30
OM	Pearson					1	.751**	.815**	.665**
	Sig. (2-tailed)						.000	.000	.000
	N						30	30	30
TOC	Pearson						1	.674**	.647**
	Sig. (2-tailed)							.000	.000
	N							30	30
TKN	Pearson							1	.315
	Sig. (2-tailed)								.090
	N								30
TP	Pearson								1
	Sig. (2-tailed)								
	N								30

****.** Correlation is significant at the 0.01 level (2-tailed).

***.** Correlation is significant at the 0.05 level (2-tailed).

Appendix 27: Correlations between water and sediment parameters from upstream to downstream area at upper Baram River in 2015

		SpH	Sand	Silt	Clay	OM	TOC	STKN	STP
Temperature	Pearson	.529**	-.251	-.079	-.085	-.320	-.181	-.471**	.174
	Sig. (2-tailed)	.003	.181	.677	.655	.085	.339	.009	.358
	N	30	30	30	30	30	30	30	30
Specific conductance	Pearson	.240	.049	-.018	.013	-.075	-.111	-.272	.193
	Sig. (2-tailed)	.202	.796	.927	.947	.694	.560	.146	.308
	N	30	30	30	30	30	30	30	30
pH	Pearson	.207	-.264	-.113	.198	.019	.229	-.118	.429*
	Sig. (2-tailed)	.271	.159	.552	.293	.920	.224	.535	.018
	N	30	30	30	30	30	30	30	30
DO	Pearson	-.123	.073	.057	.092	.038	.010	.177	-.055
	Sig. (2-tailed)	.518	.700	.763	.630	.842	.958	.349	.775
	N	30	30	30	30	30	30	30	30
Turbidity	Pearson	-.107	-.223	-.160	-.086	-.024	.112	.143	-.052
	Sig. (2-tailed)	.575	.237	.399	.653	.899	.556	.451	.783
	N	30	30	30	30	30	30	30	30
Transparency	Pearson	-.207	.237	.473**	.509**	.520**	.204	.308	.286
	Sig. (2-tailed)	.272	.207	.008	.004	.003	.280	.098	.126
	N	30	30	30	30	30	30	30	30
TSS	Pearson	.065	-.481**	-.202	-.074	-.080	.225	.118	-.026
	Sig. (2-tailed)	.734	.007	.285	.699	.675	.233	.534	.893
	N	30	30	30	30	30	30	30	30
Chl- <i>a</i>	Pearson	.020	-.005	.257	.027	-.006	-.103	.035	-.121
	Sig. (2-tailed)	.916	.978	.170	.885	.975	.586	.855	.525
	N	30	30	30	30	30	30	30	30
BOD ₅	Pearson	.061	.147	-.047	-.546**	-.426*	-.450*	-.298	-.580**
	Sig. (2-tailed)	.749	.438	.803	.002	.019	.013	.109	.001
	N	30	30	30	30	30	30	30	30
COD	Pearson	.177	-.313	-.321	-.124	.075	.413*	-.069	.360
	Sig. (2-tailed)	.349	.092	.084	.516	.693	.023	.719	.051
	N	30	30	30	30	30	30	30	30
NO ₂ -N	Pearson	-.057	.014	-.090	-.231	-.210	-.340	-.056	-.218
	Sig. (2-tailed)	.766	.940	.637	.219	.265	.066	.770	.246
	N	30	30	30	30	30	30	30	30
NO ₃ -N	Pearson	-.055	.156	-.064	-.441*	-.463**	-.582**	-.350	-.515**
	Sig. (2-tailed)	.773	.409	.737	.015	.010	.001	.058	.004
	N	30	30	30	30	30	30	30	30
NH ₃ -N	Pearson	-.391*	.559**	.232	-.004	.136	-.214	.184	-.242
	Sig. (2-tailed)	.033	.001	.218	.981	.474	.256	.331	.197
	N	30	30	30	30	30	30	30	30
Org-N	Pearson	.141	.021	-.196	-.502**	-.479**	-.494**	-.438*	-.362*
	Sig. (2-tailed)	.456	.911	.298	.005	.007	.006	.016	.049
	N	30	30	30	30	30	30	30	30
TP	Pearson	.108	.239	.043	-.441*	-.388*	-.539**	-.271	-.403*
	Sig. (2-tailed)	.570	.204	.822	.015	.034	.002	.147	.027
	N	30	30	30	30	30	30	30	30

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Appendix 28: Grain size of the soils

Name of soils	Grain size diameter (mm) (USDA, 2017)
Clay	< 0.002
Silt	0.002-0.050
Very fine sand	0.05-0.10
Fine sand	0.10-0.25
Medium sand	0.25-0.50
Coarse sand	0.50-1.00
Very coarse sand	1.00-2.00

Appendix 29: Soil textural classification of the stations from upstream to downstream area in the year 2015

Station	Texture
1	sandy loam
2	sandy loam
3	loamy sand
4	sandy loam
5	loamy sand
6	sandy loam
7	loamy sand
8	loamy sand
9	sandy loam
10	sandy loam
11	sandy loam
12	sandy loam
13	sandy loam
14	sandy loam
15	sandy loam
16	sandy loam
17	loamy sand
18	loamy sand
19	sandy loam
20	sandy loam
21	sandy loam
22	sandy loam
23	sandy loam
24	sandy loam
25	sandy loam
26	sandy clay loam
27	sandy loam
28	silt loam
29	sandy loam
30	sandy loam

Appendix 30: Paired t-test between diluted and undiluted BOD₅ ($p>0.05$)

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	BODCOD	.1120	10	.05116	.01618
	BODCODX	.0810	10	.02885	.00912
Pair 2	Ratio_Nodilute	.0914	7	.02734	.01033
	Ratio_dilute	.0686	7	.04220	.01595

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	BODCOD & BODCODX	10	.036	.921
	Ratio_Nodilute & Ratio_dilute	7	.551	.200

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
			Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	BODCOD - BODCODX	.03100	.05782	.01828	-.01036	.07236	1.695	9	.124
Pair 2	Ratio_Nodilute - Ratio_dilute	.02286	.03546	.01340	-.00993	.05565	1.706	6	.139

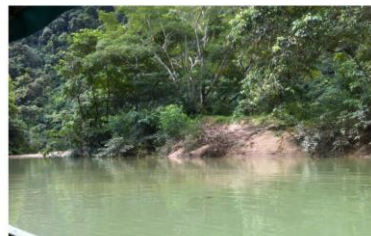
Appendix 31: Photos of sampling sites



Soil erosion at the main river
(21/01/2015, 1214)



Estuary at the downstream area
(22/01/2015, 1107)



Soil erosion at the tributaries
(22/01/2015, 0950)



Logging at the upstream main river
(29/07/2015, 1003)



Longhouses at Long Na'ah
(21/01/2015, 1215)



Transportation used by residents at Long Kesseh
(21/01/2015, 0930)



Road construction to
midstream area
(02/09/2015, 0915)



Long San's Bridge
connecting
downstream area
to midstream area
(12/01/2016, 0906)



A bridge connecting
Long Moh to their
school (29/07/2015,
1159)



Main river during
dry season
(13/03/2016, 1639)



Downstream
Tributaries during
dry season
(13/01/2016, 1343)



Main river during
dry season
(14/03/2016, 1145)



Downstream
Tributaries during
raining season
(21/01/2015, 1127)